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ARTICLES

The Biblical Underpinnings of Tit-for-Tat: Scriptural Insights into Axelrod's *The Evolution of Cooperation* 1
Charles M. North and Beck A. Taylor

Productive Capital and Christian Moral Teaching 26
Jim Halteman

SYMPOSIUM: Two Approaches to Fashioning A Christian Perspective on the Liberal Market Order

Edd S. Noell, editor

Poverty, Freedom and Economic Justice: The Need for an Extended Dialogue 39
Edd S. Noell

The Market Economy and Human Community 45
Douglas Puffert

Capitalism, Wealth and Poverty: How Should Christians Evaluate the Liberal Economic Order and its Consequences? 57
Tracy C. Miller

Poverty, Government and the Meaning of Economics 67
John P. Tiemstra

Wealth, Poverty and Human Destiny: A Selective Review 77
J. David Richardson

Two Different Worlds, We Live in Two Different Worlds 84
William F. Campbell and Andrew W. Foshee

BOOK REVIEWS

The Economics of Sin: Rational Choice or No Choice at All? 93
Samuel Cameron
Reviewed by Earl L. Grinols

continued

<i>Lifting up the Poor: A Dialogue on Religion, Poverty and Welfare Reform</i>	96
Mary Jo Bane and Lawrence M. Mead Reviewed by Sarah Hamersma	
<i>A New Protestant Labor Ethic at Work</i>	100
Ken Estey Reviewed by Todd Steen and Steve VanderVeen	
<i>Inhabiting the Land</i>	104
Andrew M. Yuengert Reviewed by Andrew Henley	

The Biblical Underpinnings of Tit-for-Tat: Scriptural Insights into Axelrod's *The Evolution of Cooperation*

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Abstract: *Axelrod (1984) identifies the tit-for-tat strategy as robustly superior to other strategies in a repeated Prisoner's Dilemma. Axelrod attributes tit-for-tat's success to its willingness to never be the first to defect, its propensity to quickly forgive previous defections, its provokable nature that quickly and reliably recognizes and punishes defection, and its clarity. This paper summarizes Axelrod's analysis of cooperation, particularly tit-for-tat's effective properties, and then frames it in the context of Christian scriptures. Are the factors that Axelrod finds most likely to lead to cooperative, or successful, behavior in social interaction also in accord with biblical mandates governing human relationships? We conclude that biblical commands regarding personal interactions are strikingly parallel to the properties that make tit-for-tat successful. JEL Codes: A13, Z12, C70 Key Words: Prisoner's Dilemma; tit-for-tat; cooperation; Christian teachings*

“If your brother sins, rebuke him, and if he repents, forgive him.” —Luke 17:3b, NIV

When should a person cooperate, and when should a person be selfish, in an on-going interaction with another person?” With this deceptively simple question, Robert Axelrod begins what has become arguably one of the most important texts, and certainly one of the most frequently cited, in the fields of behavioral economics and game theory. In his book *The Evolution of Cooperation* (1984), Axelrod lays the groundwork for what has become one of the most examined questions for study in economics and the behavioral sciences: “Under what conditions will cooperation emerge in a world of egoists without central authority?” (p. 3). The answer to this question undoubtedly has vast implications, from

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2 FAITH & ECONOMICS

private contracting in a market economy, to competition in oligopolistic markets, even to nuclear disarmament.¹

Axelrod's seminal work presents a systematic study of the *evolution* of cooperation; that is, Axelrod sets the interaction of humans, who possess potentially opposing incentives for decision making, into a context of dynamic, repeated interaction, in which cooperation may result. His question presupposes, then, that it is perhaps not in the human set of natural habits to seek out cooperation, nor is it always innate behavior for people to engage in the necessary actions to achieve cooperation's potentially rewarding outcomes. In fact, the subtext of Axelrod's book might best be summarized with the question: In some contexts, why do we observe cooperative behavior at all?²

This paper summarizes Axelrod's analysis of cooperation and then frames it in the context of biblical writings. We ask whether the factors that Axelrod finds are most likely to lead to cooperative, or successful, behavior in social interaction are also in accord with biblical mandates governing human relationships. To Axelrod's surprise, and perhaps surprising to us all, he finds that in an on-going relationship between people who have opposing but symmetric incentives—a condition that makes cooperation extremely difficult—a relatively simple strategy emerges as the most likely to elicit a cooperative outcome, a strategy named "tit-for-tat." Axelrod asserts that this relatively transparent strategy, which requires one to initiate cooperation and then to mimic the actions of one's partner, succeeds over all other strategies because the tit-for-tat strategy displays four important characteristics. As Axelrod summarizes it, the tit-for-tat strategy is, at the same time, "nice" (i.e., it does not unnecessarily seek out potential conflict), "forgiving" (i.e., it does not distribute punishment too long toward a person who has defected from cooperation), "provocable" or "retaliatory"³ (i.e., although the strategy is "nice," there also are clear repercussions for another player who defects from cooperation), and "clear" (i.e., it is a rule that is easy to implement, and another person can easily decipher the strategy's intentions). Axelrod then argues that some combination of these traits will characterize any set of strategies that are able to achieve sustained cooperation.

From this starting point, and given the apparent success of the tit-for-tat strategy in inducing cooperative outcomes, we examine whether the Christian scriptures provide support or justification for the implementation of tit-for-tat or other strategies that share its alleged strengths. To do so, we survey the Bible for specific scriptural imperatives that might support or discourage the use of strategies that, like tit-for-tat, feature the four

characteristics suggested by Axelrod. We conclude that biblical commands regarding personal interactions are strikingly parallel to Axelrod's four traits of nice, forgiving, provokable, and clear.⁴

Section I describes in detail Axelrod's experimental analyses of a repeated Prisoner's Dilemma tournament, and the successful tit-for-tat strategy. Our survey of biblical passages and Christian teachings that pertain to the characteristics of the tit-for-tat strategy appears in Section II. Section III sets forth concluding comments.

I. The Evolution and Characteristics of Cooperation

A. *Opposing Incentives and the Prisoner's Dilemma*

Modern game theory, a methodology for the study of strategic choice, attempts to cast social interaction into a tractable, necessarily reduced structure that includes combinations of "players," "strategies" (and subsequent "actions"), and "payoffs." Regardless of the complexity of the strategic situation being modeled, all *games* include these four components. *Players* are the economic or social agents who are engaged in the interaction, and these can be many or few. The choices available to these players are called *strategies*, and from this set of strategies players choose their specific *action* via some calculus that involves self-interest. Finally, the intersection of players and actions ultimately yields an outcome that has assigned to it *payoffs* to each player. Such payoffs can be cardinal in nature (e.g., specific dollar amounts of wealth), or ordinal (e.g., ordered states of the world, or utility). Once the specific application is represented as an appropriate game, it is the task of the examiner to find the "solution" or, equivalently, the "equilibrium" of the game: the likely set of actions that we expect players will choose given the incentives embedded within the game. Although not applicable in every scenario, the easiest solution technique is the identification of strategies for each player that always produce the best possible outcome (or payoff), regardless of the actions of the other players. Such strategies are considered *dominant strategies* because they dominate all other strategic choices. If all players possess a dominant strategy in their set of available strategies, then the solution, or equilibrium, of the game will entail all players choosing to "play" their dominant strategy.

Perhaps the best known game is the Prisoner's Dilemma. The popularity of the dilemma, and Axelrod's choice of it as the case study he examines, are likely the result of its broad application to many social and economic contexts.⁵ The Prisoner's Dilemma pits two players who must simultaneously choose to either "cooperate" or "defect" (i.e., not

4 FAITH & ECONOMICS

cooperate). The game is most easily represented in the 2×2 payoff matrix like the one found in Figure 1 (below):

		Player 2	
		Cooperate	Defect
Player 1	Cooperate	3, 3	0, 5
	Defect	5, 0	1, 1

Figure 1

The payoffs to each player in Figure 1 can be viewed as rankings of the four possible outcomes of the game for each player (Player 1's payoff is the first in each cell's pair). For example, Players 1 and 2 would each prefer the outcome in which they both cooperate to the all-defect outcome. Interestingly, however, note that Player 1 prefers the outcome in which she defects and Player 2 cooperates over the all-cooperate outcome, and vice versa for Player 2. This fact underscores the conflicting incentives that make cooperation difficult in this type of scenario—for each player, “defect” is the dominant strategy. Recall that a dominant strategy yields a higher payoff regardless of the actions of the other players. In the Prisoner's Dilemma, Player 1 and Player 2 both receive a higher payoff from choosing defect, no matter what action is chosen by the other player. Thus, both players have a dominant strategy, and both players prefer defection over cooperation. Under traditional theory, the solution, or equilibrium, to the game is for each player to choose to defect and receive a payoff of 1.

Before moving on, it is important to mention one more characteristic of the all-defect equilibrium. Although each player is pursuing his or her best (or, in the words of Axelrod, his or her “selfish” or egoistic) interest by choosing to defect, note that both players would be strictly better off if they could have coordinated on the all-cooperate outcome. It is, in fact, this paradoxical result that contributes to the applicability of the dilemma to other, less contrived contexts. For example, consider the case of grade inflation: each professor would enjoy most an outcome in which grades served as unbiased and accurate signals of student achievement, but to stick to such a grading scheme might be harmful to student evaluations

of the professor if other professors were adopting less stringent grading strategies. Thus, in a defensive move, each professor adopts the less stringent scheme, and all professors are worse off when grade inflation ensues. Or, consider a developing country's choice to reduce toxic pollutants. All developing countries would prefer a state of the world in which each country reduces emissions. But each individual nation has an incentive to relax environmental standards. For any individual nation to toughen standards in this context would be economic suicide. In the end, no one wins this "race to the bottom." Thus, as Axelrod states, "The Prisoner's Dilemma is simply an abstract formulation of some very common and very interesting situations in which what is best for each person individually leads to mutual defection whereas everyone would have been better off with mutual cooperation" (p. 9).⁶

B. The Economics of Cooperation

Assuming that (1) the game described above is played only once, (2) players cannot correctly anticipate other players' moves (i.e., it is played simultaneously, or players have no information on their opponent's previous moves), (3) there exist no credible commitment devices or threats to constrain behavior, and (4) no player can change the payoffs of another, the all-defect outcome is a theoretical certainty and an experimental regularity. However, such an outcome goes directly contrary to casual observation: we do often observe agents who have opposing incentives but who nevertheless engage in successful cooperation. How does such cooperation emerge? The most common way theoretically to amend the preceding four assumptions is to relax the assumption of one-time play. Instead of assuming that players engage in a static, one-shot opportunity to play the game, we assume that the game may be played time and time again by the same pair of players. By introducing the notions of dynamic interaction and repeated play, players engaged in the dilemma must now account for a concept removed from the static version of the game: the future.

The introduction of a future into the dilemma only accentuates the suboptimality of the all-defect outcome. If players continue period after period to experience the stinging penalty for defection, then perhaps they will "learn" to cooperate. However, what makes the future such a powerful force for cooperation is not just the opportunity to reap the higher rewards from cooperation, but, perhaps more importantly, the potential costs of defection. That is, if players are engaged in the dilemma and enjoying the fruits of cooperation, why aren't the one-time gains from defection still

6 FAITH & ECONOMICS

enticing? If a player knows (or anticipates) that his partner in the game will again cooperate, why will he not defect and capitalize on his partner's commitment to cooperate? The answer must be that he anticipates some negative outcome from his defection, perhaps a punishment levied by his trusting partner.

In an economic sense, as the game is played over and over into the unknown and potentially infinite future, cooperation will be maintained so long as the benefits from cooperation (i.e., the sustained cooperative payoffs received period after period) outweigh the benefits from defection (i.e., the one-time increase in the payoff in the period of defection plus the subsequent payoffs associated with the outcome, determined in part by the penalty enacted by the other player).⁷ In game theory, players are assumed to adopt certain *trigger strategies* in response to defection by the other player from the cooperative outcome. These trigger strategies are complete contingency plans that outline specifically what a player will do in response to a breakdown in cooperation caused by another player. Such punishment strategies must identify (1) when a breakdown in cooperation has occurred, (2) what strategy will be played in response to a breakdown, and (3) how long such a response will last. For example, a common strategy assumed by theorists is the *grim strategy*. When playing the grim strategy, a player starts the game by choosing to cooperate, and she continues to cooperate, period after period, as long as her rival also chooses to cooperate. But if and when her rival chooses to defect, the player who adopts the grim strategy promises to switch and choose to defect forever after, thus inflicting upon her partner (and herself) lower payoffs under the all-defect outcome.

Consider two extremes in the context of players who employ the grim strategy: (1) the case in which a player does not value the future at all, and thus does not value any payoff or penalty received or incurred in the future, and (2) the case in which a player values the future very much, and thus places a relatively high value on future rewards or penalties from cooperation or defection. In the first case, the player discounts the future so much that he effectively "lives for today." Such a player would always defect because he would place a higher value on the immediate gains from defection than on the future benefits from cooperation.⁸ He would discount the importance of future punishment that may follow his defection. On the other hand, a player who places a high value on the future would carefully consider the ramifications of her defection from cooperation. Unlike her *carpe diem* counterpart, she would be concerned about the long-term threat of low payoffs associated with mutual defection, rather than the one-time gain derived from unilateral defection. Thus, a general proposition that is well-documented in the economics literature is that, as the rate at which players discount the future increases, cooperation is

less likely to be maintained. Put another way, cooperation is more likely to be maintained if players value the future sufficiently.⁹ As it turns out, this result can be generalized to any trigger strategy employed in the face of defection, not just those that are very tough, like the grim strategy.¹⁰

C. The Emergence of Cooperation and The Tit-for-Tat Strategy

At the time Axelrod wrote his book, game theorists well understood that cooperation was difficult if not impossible to obtain in the one-shot Prisoner's Dilemma, and that players must sufficiently value the future in order to achieve and maintain cooperation in the repeated Prisoner's Dilemma. Axelrod's ingenious contribution was to put various playing strategies to the test in an experimental setting. Such a tournament, he envisioned, would yield new valuable insights into the characteristics of strategies that were most likely to do well in the repeated dilemma.

The grim strategy described above is actually quite simple. Other strategies that detect defection and subsequently punish defectors can be quite complex. Under the grim strategy, defection is detected immediately, and punishment is handed out in the next period, but rules for defection that depend on the "history" of the game can be more complicated. For instance, perhaps some allowance can be made for "mistakes" made by other players (say, when the other player accidentally plays defect, or plays defect to begin the game). If such an allowance is made, a more reasonable trigger strategy might employ punishment only after defection has occurred two or three times in a row. The punishment component of the trigger strategy can also be more lenient than in the grim strategy, which punishes forever. Punishment might last for only one period, or a few periods, to get the point across that cooperation is preferred, but defection will not be allowed.

Players can actually have strategies that are not just reactive in the face of opposing players' defections, but also proactive—that is, strategies that call for preemptive defection. This has important implications for later sections of this paper. Although such strategies are not technically trigger strategies (which are only *triggered* by someone else's defection), they are nonetheless playing strategies that may incorporate detection and punishment components, in addition to a preemptive defection component. As an example of such a complex playing strategy, consider a strategy that uses probabilities to determine when to defect, or when to punish. Such a rule can be totally random, with equal probabilities of cooperation or defection in each turn of the game, or it can be more complex and use the pattern of outcomes in the history of the game to determine what to do next.¹¹

Given so many nuanced alternatives, Axelrod wondered, "What is the best

8 FAITH & ECONOMICS

strategy?" (p. 14). He immediately determined that the answer to the question is conditional upon whether the other player's strategy allows for the possibility of mutual cooperation. Mutual cooperation will not be the outcome if one of the two players employs a strategy in which defection is the rule. To determine which strategies might foster cooperation, or, more precisely, to examine which strategies performed better against other strategies in a repeated Prisoner's Dilemma (the exact game described in Figure 1), Axelrod set out to construct a computerized tournament. Axelrod writes,

In a computer tournament, each entrant writes a program that embodies a rule to select the cooperative or noncooperative choice on each move. The program has available to it the history of the game so far, and may use this history in making a choice. If the participants are recruited primarily from those who are familiar with the Prisoner's Dilemma, the entrants can be assured that their decision rule will be facing rules of other informed entrants. Such recruitment would also guarantee that the state of the art is represented in the tournament (p. 30).

Axelrod invited fourteen scholars to participate, each of whom was quite familiar with game theory and the Prisoner's Dilemma. The contestants represented diverse fields of study, including psychology, economics, political science, mathematics, and sociology. Each contestant's computer program described precisely how to play each move and was paired against each of the thirteen other programs in a round-robin tournament. Each game lasted exactly 200 moves.¹² Additionally, each program was also pitted once against itself and once against a program that randomly chose to cooperate and defect. For robustness, the entire round-robin tournament was run five times, and the results from all 120,000 moves and 240,000 separate choices were accumulated.

The entries for the computer tournament spanned the gamut of characteristics, such as complexity, length of the computer program, the degree of cooperation built into the strategy. Interestingly, neither the author's discipline of study nor the length or complexity of the program proved to be useful predictors of success. In the end, the simplest of all of the programs, and the best known playing strategy, the simple "tit-for-tat" strategy, won the tournament. The tit-for-tat strategy starts the repeated Prisoner's Dilemma by cooperating in the first period, then mimicking the other player's moves in the next period, and so on. Thus, tit-for-tat rewards cooperation with cooperation and punishes defection with defection. To put the results into some perspective, scores for a particular strategy from any given pairing could range from zero to 1,000 points, a perfect "cooperation" score, occurring only when both players cooperate at each move, is 600, and the all-defect score, occurring only when both players

defected at each move, is 200. Tit-for-tat's average score in the tournament was 504. The next highest average score was 500 for a slight variant of tit-for-tat, and the lowest average score was 276 for the random strategy.

Each of the eight top-ranking entries employed strategies dictating that they would never be the first to defect. None of the six lowest-scoring entries adopted this strategy—they each defected first. Moreover, the average scores for these never-first-to-defect strategies ranged from 472 to 504, while the highest-ranking first-to-defect strategy earned an average score of only 401 points. The comparative success of the never-first-to-defect strategies comes primarily from their games with themselves and the similar cooperative strategies. When pairing two strategies in which first-defection is not an option, neither will defect during the course of the game, and each will achieve the full-cooperation score of 600.

Because the effectiveness of a particular strategy “depends not only on its own characteristics, but also on the nature of the other strategies with which it must interact” (p. 40), Axelrod called for a second tournament. This tournament would

provide substantially better grounds for insight into the nature of effective choice in the Prisoner's Dilemma. The reason is that the entrants to the second round were all given the detailed analysis of the first round.... Thus they were aware not only of the outcome of the first round, but also of the concepts used to analyze success, and the strategic pitfalls that were discovered. Moreover, they each knew that the others knew these things. Therefore, the second round presumably began at a much higher level of sophistication than the first round, and its results could be expected to be that much more valuable as a guide to effective choice in the Prisoner's Dilemma (pp. 40–41).

The second tournament involved sixty-two entries, and the participants of the first tournament were invited to participate again.¹³ Tit-for-tat, as mentioned previously, was the simplest program submitted in the first tournament, and it won that tournament. It was again the simplest program submitted in the second tournament, and it again won. “Even though all the entrants to the second round knew that tit-for-tat had won the first round, no one was able to design an entry that did any better” (p. 42).

Finally, to again test the robustness of his results, Axelrod experimented with an “evolutionary” simulation. In this simulation, extra copies of each of the computer programs were placed back into the pool of programs after each round in the round-robin tournament based on each strategy's relative success against the existing pool of strategies. Thus, over time, relatively successful strategies were rewarded with more “twins” in the pool, whereas relatively

10 FAITH & ECONOMICS

unsuccessful strategies dwindled as a percentage of the overall population. For instance, after the first round of the round-robin tournament, tit-for-tat would become better represented in the overall population of strategies relative to the random strategy. The results from this evolutionary experiment were impressive: tit-for-tat never lost its first-place standing in the simulation. Thus, Axelrod concludes that although “there is no absolutely best rule independent of the environment...the empirical successes of tit-for-tat [demonstrate] that it is a very robust rule: it does very well over a wide range of environments” (p. 53).

D. The Characteristics of Tit-for-Tat

What, then, accounts for the success of the tit-for-tat strategy in the context of the repeated Prisoner’s Dilemma? Axelrod stops short of any kind of rigorous empirical framework, such as factor analysis or regression, to discover the answer. Rather, Axelrod goes to great lengths to describe qualitatively the characteristics, or properties, of the tit-for-tat strategy, and other relatively successful strategies, that contribute to their success. He writes,

What accounts for tit-for-tat’s robust success is its combination of being nice, retaliatory, forgiving, and clear. Its niceness prevents it from getting into unnecessary trouble. Its retaliation discourages the other side from persisting whenever defection is tried. Its forgiveness helps restore mutual cooperation. And its clarity makes it intelligible to the other player, thereby eliciting long-term cooperation (p. 54).

As mentioned previously, one of the few inferences Axelrod made from the first tournament was that “nice” strategies performed well, placing in the top eight positions. Axelrod defines being nice as the “avoidance of unnecessary conflict by cooperating as long as the other player does” (p. 20), or “never being the first to defect” (p. 33). In fact, there was a pronounced difference in the average scores of nice strategies and their meaner counterparts. The nice rules “did well in the tournament largely because they did so well with each other, and because there were enough of them to raise substantially each other’s average score” (p. 35). An example of an underperforming not-so-nice strategy that was a slight variant of tit-for-tat was a strategy that, like tit-for-tat, always defected immediately after the other player defected, but, unlike tit-for-tat and the other nice strategies, preemptively defected 10 percent of the time after the other player cooperated, occasionally exploiting the other player’s good will.

Why does being nice play such an important role? Axelrod posits that it is because so many of the strategies were, unlike the tit-for-tat strategy,

unforgiving. As Axelrod states, “*Forgiveness* of a rule can be informally described as its propensity to cooperate in the moves after the other player has defected” (p. 36, emphasis added). Tit-for-tat is extremely forgiving, especially compared to its grim cousin. When playing tit-for-tat, defection by the opponent is met with defection in the next period, but if the opponent corrects his mistake, tit-for-tat rewards this correction by immediately (in the next period) choosing cooperation again. In fact, of all of the nice rules submitted in the first tournament, the one that performed worst, the grim strategy, was the least forgiving, forever punishing an opponent for deviating from the cooperative outcome. Interestingly, a more forgiving version of tit-for-tat, tit-for-two-tats, would have won the first tournament had it been submitted.¹⁴ Rather than defecting the period immediately following a rival’s defection, tit-for-two-tats waits until the other player defects twice consecutively, thus not punishing an opponent for isolated defections. Axelrod concludes his discussion of forgiveness thus:

The [success] of [tit-for-two-tats] should serve as a warning against the facile belief that an eye for an eye is necessarily the best strategy.... The implication of this finding is striking, since it suggests that even expert strategists do not give sufficient weight to the importance of forgiveness (p. 39).

As noted below, though, tit-for-two-tats was not as robustly successful in the second tournament as tit-for-tat because tit-for-two-tats is too easily exploitable.

One more point is worth highlighting at this stage in light of the discussion so far on the apparent importance of being nice and forgiving. The degrees to which strategies that are pitted against one another are nice and/or forgiving is important because of the potential interaction between these two characteristics. That is, there are multiple levels of analysis in which being nice and forgiving (or mean and unforgiving) can come back to benefit (or harm) a player. Axelrod calls these multiple levels of interaction “echo effects” (p. 38). Such echo effects can be extremely important in an environment of mutual power. Any successful strategy must take account of at least three levels of interaction. First, a successful strategy must consider the first action: defect or cooperate. This is easy enough. Second, a successful strategy must evaluate the repercussion of the first action: specifically, a defection may elicit a negative response in the form of a defection by the other player. Axelrod noticed that most strategies recognized the importance of these first two levels of interaction. However, Axelrod points to an important, but often ignored, third and deeper level of interaction: “[taking] into account the fact that in

12 FAITH & ECONOMICS

responding to the defections of the other side, one may be repeating or even amplifying one's own previous exploitive choice....[T]he real costs may be in the tertiary effects when one's own isolated defections turn into unending mutual recriminations" (p. 38). In other words, Player A may be forced to defect in response to Player B's defection, which was, in turn, prompted by Player A's original defection—Player A's original defection actually comes back to haunt him.

In Axelrod's analysis, nice and forgiving strategies succeeded where mean and unforgiving strategies did not. But Axelrod was curious about whether there was some other property that could help distinguish among the nice strategies. He found that nice strategies that promptly and reliably responded to a challenge by another player generally outperformed other nice strategies that were either too slow to respond or could not be relied upon to respond to defection. Axelrod writes, "A rule can be called *retaliatory* if it immediately defects after an 'uncalled for' defection from the other....The point, however, is that unless a strategy is incited to an immediate response by a challenge from the other player, the other player may simply take more and more frequent advantage of such an easygoing strategy" (p. 44). Axelrod acknowledges that what is meant by "uncalled for" is not precisely determined, but it appears to align with the notion of preemptive defection in the face of potential cooperation, that is, not being nice.

Axelrod notes that there were a number of strategies submitted in the second tournament that deliberately attempted strategic defections to see what they could get away with. Interestingly, what distinguished the more successful nice strategies from the less successful ones was their ability to cope with these challengers. For example, the more forgiving variant of tit-for-tat that would have won the first round if submitted, tit-for-two-tats, was soundly beaten in the second round by a rule that was written expressly to beat it. The rule that beat tit-for-two-tats was designed to look for "softies," or those strategies that were not sufficiently provokable. It started the game by defecting on the first move in order to test the other's response. If the other player ever defected, it "apologized" by choosing to cooperate and playing like tit-for-tat for the rest of the game. Otherwise, it cooperated on the second and third moves of the game, and then defected again to test the opponent, and the process started over again. Because tit-for-two-tats defects only after the other player defects twice in a row, and because this new rule never defected twice in a row, tit-for-two-tats always cooperated with this sneaky rule, and was exploited on every third move with a defection, essentially because it was not sufficiently provokable. Summarizing, Axelrod writes,

So while it pays to be nice, it also pays to be retaliatory. Tit-for-tat combines these desirable properties. It is nice, forgiving, and retaliatory. It is never the first to defect; it forgives an isolated defection after a single response; but it is always incited by a defection no matter how good the interaction has been so far (p. 46).

A final property to which Axelrod attributes tit-for-tat's robust success is its clarity. The beauty of tit-for-tat is that other rules anticipate its presence and must, therefore, be designed to do well with it, which requires cooperating with it, which in turn benefits tit-for-tat. For example, even the devious rule described above that was written to beat tit-for-two-tats would quickly apologize to tit-for-tat. "Any rule which tries to take advantage of tit-for-tat will simply hurt itself" (p. 53). Axelrod presents three conditions of nonexploitability that are satisfied by tit-for-tat. First, the possibility of encountering tit-for-tat is salient. Second, once encountered, tit-for-tat is easy to recognize. Third, once recognized, tit-for-tat's nonexploitability is easy to appreciate. In Axelrod's opinion, these three conditions contribute to the clarity of tit-for-tat.

Later in *Evolution*, when Axelrod distributes advice for potential participants in and reformers of social interaction like that described by the Prisoner's Dilemma, Axelrod extends his notion of clarity by admonishments not to be "too clever" in dealings with others. Destructive cleverness can show up in overly sophisticated rules that make too many complex inferences about the other player's behavior, and thus potentially make harmful mistakes; in rules that are simplistically harsh in distributing punishment, like the grim strategy, which may give up too quickly on an opponent who attempts defection but is willing to back off quickly; and in rules that are just incomprehensible to the other player. As Axelrod states, "When you are using tit-for-tat, the other player has an excellent chance of understanding what you are doing...[and] the other player can easily see that the best way to deal with tit-for-tat is to cooperate with it" (pp. 122–123).¹⁵

II. Cooperative Traits in Scripture

In the previous section, we detailed the desirable properties that Axelrod identifies in the successful tit-for-tat strategy for repeated Prisoner's Dilemma tournaments. In this section, we survey Christian scriptures and teachings on interpersonal relationships that relate, pro or con, to the four properties of the tit-for-tat strategy outlined by Axelrod.

Before we begin, a few caveats are in order. First, our discussion of the potential similarities between biblical teachings and the positive characteristics of the tit-for-tat strategy should not be taken as a presumption on our part

14 FAITH & ECONOMICS

that Axelrod has any intention of drawing such connections. Although, in our opinion, there are many theological inferences one could draw out of the Axelrod text, we have no reason to suspect that Axelrod had such parallels in mind. Second, we make no claim that the authors of biblical writings had in mind any forms of the Prisoner's Dilemma or potentially successful strategies in such a setting. Third, we are not arguing that the Bible advocates the tit-for-tat strategy. Rather, we assert that the biblical teachings regarding interpersonal relationships espouse behavior that works well in a variety of settings, including settings like the Prisoner's Dilemma. In this way, our view of these teachings is much like the modern scientific view of the dietary rules found in the Old Testament: while the purpose of such rules perhaps was not primarily to foster improved public health, careful adherence to these dietary rules would have had such salubrious effects.

In our view, the biblical teachings that we discuss below are broader than, and applicable to more than, just the Prisoner's Dilemma and tit-for-tat. Our discussion of Axelrod in the previous section is a motivation for the broader analysis of interpersonal relationships and cooperation presented below. However, as a helpful device, we frame our biblical analysis around the four successful traits of the tit-for-tat strategy as outlined by Axelrod. With these caveats in mind, we turn now to our examination of biblical writings. We address each of the four traits separately, even though they are interrelated in many ways.

A. "Nice"

Recall that the tit-for-tat strategy was never the first to defect in the repeated Prisoner's Dilemma. In fact, in the first tournament, each of the top eight strategies was "nice" in this way. In this same vein, Axelrod emphasizes the characteristic of avoiding unnecessary conflict. Immediate biblical parallels include the notions of peace, contentment (with cooperation), not coveting wealth or gain (which may provoke someone to defect from cooperation), good faith (or trustworthiness), honest dealings, and fair treatment.

Not surprisingly, many biblical imperatives on these topics are contained within the Wisdom Literature (Psalms, Proverbs, Ecclesiastes, etc.). An example from Proverbs is typical: "If a man pays back evil for good, evil will never leave his house" (Prov. 17:13).¹⁶ Similarly, Psalm 34:14 instructs: "Turn from evil and do good; seek peace and pursue it." Immediate parallels to Axelrod's analysis are apparent. First, the notion of paying back evil for good is equivalent to defecting in response to cooperation. Likewise, turning from evil and pursuing peace reflect the ideas of actively discouraging defection and seeking cooperation. Interestingly, many of the strategies submitted

to the Prisoner's Dilemma tournament that were not nice, and at the same time extremely retaliatory, resulted in outcomes characterized by persistent defection. Recall that Axelrod warned against seeking conflict because such preemptive defections could result in sustained noncooperation via harmful echo effects. In a sense then, for the person who is first to defect, "evil will never leave his house."

From the New Testament, we find similar warnings against seeking conflict, especially when cooperation is called for. For instance, 1 Timothy 6:3–10 provides a warning of the consequences of ungodly behavior, including the initiation of conflict:

If anyone teaches false doctrines and does not agree to the sound instruction of our Lord Jesus Christ and to godly teaching, he is conceited and understands nothing. He has an *unhealthy interest in controversies and quarrels* about words that result in envy, strife, malicious talk, *evil suspicions and constant friction* between men of corrupt mind, who have been robbed of the truth and who think that godliness is a *means to financial gain*.

But godliness with *contentment* is great gain. For we brought nothing into the world, and we can take nothing out of it. But if we have food and clothing, we will be content with that. People who want to get rich fall into temptation and a trap and into many foolish and harmful desires that *plunge men into ruin and destruction*. For the love of money is a root of all kinds of evil. Some people, eager for money, have wandered from the faith and pierced themselves with many griefs (emphasis added).

One of the best known of all scriptures is the Golden Rule: "So in everything, do to others what you would have them do to you, for this sums up the Law and the Prophets" (Matt. 7:12). As no player in the Prisoner's Dilemma would desire to have her cooperation met with exploitative defection, so should no player, according to this biblical imperative, defect in response to cooperation. A common humorous misstatement of the Golden Rule actually captures exactly the wrong type of behavior: "Do unto others *before* they do unto you." Such a philosophy reveals a basic lack of trust and advocates anticipatory defection, which in Axelrod's analysis led to destructive future repercussions and chronic defection.¹⁷

B. "Forgiving"

In addition to being nice, the tit-for-tat strategy is also quick to forgive. Recall that even after a multitude of defections by his partner, the player who adopts the tit-for-tat strategy will acknowledge a single attempt at cooperation

16 FAITH & ECONOMICS

with the proverbial olive branch and will reciprocate with cooperation. Such a propensity to cooperate in the moves after the other player has defected can yield better outcomes after cooperation is reinitiated than strategies that “carry the grudge” for more periods (e.g., recall the grim strategy, which is nice but not at all forgiving).

There should be little doubt that biblical teachings place a great emphasis on the concept of forgiveness of others. A few references to the teachings of Jesus suffice to make this point. In the verse that provides this paper’s epigraph, Jesus succinctly teaches that if a brother sins and repents, he is to be forgiven (Luke 17:3b). Another widely known biblical passage is the Parable of the Prodigal Son (Luke 15:11–32). Recall that in the parable the younger son asks for and receives his inheritance from his father, which he then squanders through “wild living” in a “distant country.” When the son finds himself envying even the food that the pigs eat, he “comes to his senses” and returns to his father with the intention of asking to serve as a hired hand. His father meets the son’s repentance with complete forgiveness and a party celebrating the younger son’s return. Even though this is primarily a story to demonstrate God’s forgiveness of a repentant sinner, to the extent that humans are to mimic the character of God, it illustrates how people should respond to the repentance of others. In the parable, the younger son reinitiates cooperation and the father immediately forgives with no additional consequences or requirements.¹⁸ The father’s response neatly captures Axelrod’s concept of the type of forgiveness that leads to success in the Prisoner’s Dilemma.

Contrast the response of the older son in the Parable of the Prodigal Son with that of the father. Whereas the father immediately forgave the younger son, and thus engaged in an immediate cooperative response, the older son “became angry” at the father’s forgiveness and “refused to go in” to the party. According to the father in the parable, the older son’s response was inappropriate because it was too focused on the wrong done to the family, and not focused enough on the return of the prodigal. In this parable, Jesus commends certain behaviors while discouraging others. In particular, Jesus commends the younger son’s willingness to return to a state of cooperation after making the unwise decision to defect. Jesus also commends the father’s willingness to forgive immediately and unconditionally the younger son’s defection. Perhaps overlooked is that Jesus even commends the older son for his history of cooperation while his younger brother was defecting. However, Jesus also is critical of the older son’s hesitance to reciprocate cooperation as quickly as the father did. An implication is that people who employ the “older brother” approach to forgiveness may not fare as well as those who subscribe to the “father” approach. Recall Axelrod’s judgment that “even expert strategists

do not give sufficient weight to the importance of forgiveness” (p. 39). These lessons imply that the commended behaviors in the parable result in better outcomes, which is consistent with the findings of Axelrod.

Our final example is perhaps the first to leap to mind for many when thinking about Christian teaching on forgiveness. In the Sermon on the Mount, Jesus teaches, “You have heard that it was said, ‘Eye for eye, and tooth for tooth.’ But I tell you, Do not resist an evil person. If someone strikes you on the right cheek, turn to him the other also” (Matt. 5:38–39). The meaning for forgiveness is obvious.¹⁹ What is less clear from this passage is whether biblical teaching is consistent with Axelrod’s third trait, provocability. We turn to this trait next.

C. “Provocable”

Practice reciprocity: this is one of the main themes of Axelrod’s analysis. In fact, as Axelrod gives practical advice to players engaged in situations like the Prisoner’s Dilemma, he explicitly advocates reciprocity. Importantly, in the Prisoner’s Dilemma, reciprocity demands meeting cooperation with cooperation *and* defection with defection. Some Christians may react initially with a moral objection to the idea that a Christian in a Prisoner’s Dilemma-type situation *should* ever “defect.” Such an objection is likely the result of the name placed on the strategy in the classic story told to explain the payoff structure (see footnote 5). However, the strategies employed by both players in the Prisoner’s Dilemma could just as easily be named “left,” “right,” “up,” and “down;” there is no necessary moral content deriving from the names placed on the strategies. Thus, Christians should not object to the idea of being provokable solely because one of the two strategy choices is named “defect” in some variations of the game.

More importantly, an unfortunate consequence of the simple 2×2 structure of the Prisoner’s Dilemma game is that there is no opportunity to analyze multidimensional punishment strategies. The degree to which cooperation should be reciprocated was addressed above in our discussions of being nice and forgiving. What is less clear from Axelrod’s analysis is how punishment should be levied against a defector in a game richer in strategic options than the Prisoner’s Dilemma. For example, strategies available in a more complex game could include varying degrees of cooperation and defection, and even exit from the game. None of these is an option in the simple version of the Prisoner’s Dilemma. Even so, in the context of the Prisoner’s Dilemma, Axelrod asks whether

always doing exactly one-for-one is the most effective balance. It is hard to say because rules with slightly different balances were not submitted. What is clear is that extracting more than one defection for each defection

18 FAITH & ECONOMICS

of the other risks escalation. On the other hand, extracting less than one-for-one risks exploitation (p. 119).

Axelrod's computer tournaments can thus provide insight into more complex games, but they do not test such insights in the same thorough way that interaction in the Prisoner's Dilemma framework was tested.

We acknowledge that Jesus' command to turn the other cheek contains no explicit exception for any other response whatsoever, great or small. In the same way, *agape* love "is not easily angered" (Rom. 13:5); indeed, the King James and New American Standard translations both say that love is not easily "provoked." Even so, God's own nature suggests a justice-based cycle of defection and punishment, followed by cooperation and restoration. This cycle is exemplified by the Hebrews' sacrificial system. Sin can be viewed as the ultimate defection, a defection that immediately withdraws a person from the fellowship of the creator. Because God is just, He cannot offer fellowship to sinful humans; such a withdrawal can be viewed as God's noncooperative response designed to bring people back into His presence. Because God is loving, He created a sacrificial system (and eventually the ultimate sacrifice of Jesus) through which people can be cleansed and thereby returned to fellowship (cooperation) with God, following which God faithfully restores humans to Himself.

It is also true that God disciplines those whom He loves. For example, Proverbs 3:11–12 says, "My son, do not despise the Lord's discipline, and do not resent his rebuke, because the Lord disciplines those he loves, as a father the son he delights in." Invoking this passage, the author of Hebrews elaborates on God's discipline of His children:

Endure hardship as discipline; God is treating you as sons. For what son is not disciplined by his father? . . . God disciplines us for our good, that we may share in his holiness. No discipline seems pleasant at the time, but painful. Later on, however, it produces a harvest of righteousness and peace for those who have been trained by it (Heb. 12:7, 10b–11).

Certainly then, God is provokable in His relationships with humans, in that He punishes those who sin and grants salvation to those who believe. And it is true that believers are called to imitate God in their conduct (Eph. 5:1). Thus, we might conclude that we are required to respond to sins of others in the same manner God would. However, unlike God, we are prone to err in deciding how God would respond to sin in any given instance, with our own sinful natures likely to prod us into an inappropriate, sinful retaliation that fails to reflect both God's love and His discipline. While Jesus certainly had the authority to drive the money changers from the temple (Mark 11:15–17), he commands

us to turn the other cheek. At a minimum, we believe that Christians should be careful in extending the biblical command to be Christlike to the point of assuming ourselves to be the instrument of God's discipline.

Because of the potential danger that people might justify their own provocation by the nature of God's judgment on and discipline of His children, we also examine scriptures that address how people should interact with one another. Jesus' words in this paper's epigraph from Luke 17:3b instruct a person to rebuke a sinner, while also forgiving after repentance. In the same way, Jesus says in Matthew 18:15–17,

If your brother sins against you, go and show him his fault, just between the two of you. If he listens to you, you have won your brother over. But if he will not listen, take one or two others along, so that 'every matter may be established by the testimony of two or three witnesses.' If he refuses to listen to them, tell it to the church; and if he refuses to listen even to the church, treat him as you would a pagan or a tax collector.²⁰

Similarly, Paul writes to Titus:

But avoid foolish controversies and genealogies and arguments and quarrels about the law, because these are unprofitable and useless. Warn a divisive person once, and then warn him a second time. After that, have nothing to do with him. You may be sure that such a man is warped and sinful; he is self-condemned (Tit. 3:9–11).

These passages suggest that the Bible recognizes an appropriate level of response to wrongful acts committed by others in derogation of an interpersonal relationship.

Moreover, there is a clear biblical call to be good stewards of what God provides. In the Genesis account, God commands humans to "rule over" and "subdue" His creation (Gen. 1:26–29). The Parable of the Talents (Matt. 25: 14–30) instructs people to be responsible in their stewardship. In the parable, a master leaves his three servants behind as he goes on a long journey, giving them each some money to manage in his absence. The two servants who are able to generate a return on the money entrusted to them are rewarded as "good and faithful servants," while the one who buried the money in the ground rather than put the money to work was chastised as a "wicked, lazy servant."

It is difficult to envision how a person would be a good steward of God's resources if she allowed those resources to be stolen on a regular basis. It seems consistent with biblical teachings that those who are exploited need not forever assent to such exploitation. For example, when Ananias and Sapphira attempted to deceive the early church regarding the price at which they had sold land for the benefit of the church, Peter confronted each of them in turn

20 FAITH & ECONOMICS

(Acts 5:1–11). Of course, Peter stated that Ananias had “not lied to men but to God” (Acts 5:4), and it was God, not Peter, who struck down Ananias and Sapphira. But the story of Ananias and Sapphira suggests that individuals in positions of responsibility may confront others who are dealing dishonestly.

A few hypothetical examples will further demonstrate how responsible stewardship sometimes entails being provokable:

- A manufacturer regularly purchases parts from a supplier. In recent months, the supplier has consistently delivered substandard parts, despite the manufacturer’s repeated complaints. At some point, good stewardship requires the manufacturer to end his relationship with the supplier rather than continue to be exploited.
- A wholesaler sells to retailers on credit. One retail customer falls behind on his payments. Good stewardship would not allow credit sales to this customer to continue indefinitely. Rather, the wholesaler should require payment on past balances, limit future sales to an advance-payment basis, or possibly terminate the relationship with the customer.
- A professor observes a student cheating on a quiz. On the first instance, the professor gives the student the benefit of the doubt and does nothing. However, on a second occurrence of observed cheating, the professor, who is a steward of the integrity of the course and protective of the honest efforts put forth by other students, confronts the student and issues an appropriate punishment.

Each of these examples involves a person who is provoked to some response by the noncooperative behavior of another. These responses are not driven by vengeful motives (as the notion of retaliation might imply), but rather by a sincere attempt and desire to be a good steward in the face of noncooperative acts. Importantly, these provoked responses are efforts to restore cooperation, similar to the willingness of tit-for-tat to switch from defection to cooperation as soon as the other player returns to cooperation.

Overall, the text of the Bible reflects a delicate balance between forgiving others and holding others accountable for sin that is similar to Axelrod’s proposed balance of reciprocity in cooperating and defecting. As the Teacher of Ecclesiastes says, “There is a time for everything, and a season for every activity under heaven: . . . a time to plant and a time to uproot, a time to kill and a time to heal, a time to tear down and a time to build, . . . a time to tear and a time to mend, a time to be silent and a time to speak, a time to love and a time to hate, a time for war and a time for peace” (Eccl. 3:1–3, 7–8). Likely, there is also a time to cooperate and a time to defect.

D. “Clear”

The final trait that is critical to the success of tit-for-tat in Axelrod’s computer tournaments is clarity. Clarity is essential both because it does not seek to trick others and because others can easily figure out the strategy being employed. Biblical teachings also advocate that people deal with each other with clarity. Several passages in Proverbs praise honesty and criticize dishonesty: “The plans of the righteous are just, but the advice of the wicked is deceitful” (Prov. 12:5); “He whose walk is upright fears the Lord, but he whose ways are devious despises him” (Prov. 14:2); and “A truthful witness does not deceive, but a false witness pours out lies” (Prov. 14:5). Throughout the Old Testament, Israel is chastised for the dishonesty of its people and its leaders (e.g., Lev. 19:35–36, Isa. 1:23, Hos. 4:2, Amos 8:5). In an admonition against swearing oaths, Jesus instructs, “Simply let your ‘Yes’ be ‘Yes,’ and your ‘No,’ ‘No;’ anything beyond this comes from the evil one” (Matt. 5:37). Thus, the Christian scriptures teach the importance of honesty in all conduct, which in turn leads to the type of clarity that Axelrod finds will sustain cooperation.

III. Conclusion

In this paper, we have suggested that there are dramatic parallels between the way that the Bible teaches people to interact with each other and the traits of the tit-for-tat strategy that led it to be robustly successful in the computer tournaments described in Robert Axelrod’s *The Evolution of Cooperation*. The keys to tit-for-tat’s success are that it is nice, forgiving, provocable, and clear. Each of these facets of behavior is mirrored by scriptural narratives of God’s interaction with His people and biblical commands that govern the nature of relationships between people. We conclude that the rules for interpersonal interactions set forth in the Bible are likely to lead to better and more lucrative outcomes in many economic situations because they induce cooperation among individuals despite ever-present incentives to defect. Indeed, the fact that people live finite lives—and thus do not play an infinitely repeated game—suggests that a moral code imposed by an external authority may be an important component of generating cooperative outcomes in interpersonal relationships when the endgame is in sight.

Fukuyama (1995) argues that the central requirement for development of capitalistic enterprises like the modern corporation was a high level of societal trust in others. In societies featuring high levels of trust, individuals were willing to engage in the impersonal transactions necessary for the accumulation of capital, and innovator-entrepreneurs were willing to entrust their firms to professional managers rather than keep business matters

22 FAITH & ECONOMICS

entirely within the extended family. Fukuyama's definition of "trust" is quite germane to our discussion: "Trust is the expectation . . . of regular, honest, and cooperative behavior, based on commonly shared norms," on the part of the members of a community (p. 26). Comparing this definition to tit-for-tat's four traits, "regular" and "honest" both suggest "nice" and "clear," whereas the expectation of "cooperative behavior" is the central theme of Axelrod's research. These similarities are particularly worth noting because Fukuyama does not cite Axelrod at all. Yet, Fukuyama's central premise is that the evolution and expectation of cooperation are key cultural components of a prosperous economy. The power of Fukuyama's premise when viewed through the lens of cooperation raises important questions about the role of religion in fostering a culture favorable to economic growth. Such questions, while intriguing, will wait for another day.

Endnotes

- 1 As Axelrod (1997) states, *Evolution* "allowed a very large variety of studies to be undertaken in a common framework" (p.xi). This common framework "has allowed political scientists, economists, sociologists, philosophers, mathematicians, computer scientists, evolutionary biologists, and many others to talk to each other" (p.xi).
- 2 Although not explicitly stated in *Evolution*, Axelrod's motivation for studying the Prisoner's Dilemma was "to find out how cooperation could be promoted in international politics, especially between the East and the West during the Cold War" (Axelrod 1997, p.5).
- 3 Axelrod uses the words "provocable" and "retaliatory" interchangeably. Due to the negative connotation inherent in the term "retaliatory," we will use the term "provocable" whenever possible when discussing this trait. Whereas "provocable" implies an ability to be provoked into a response, "retaliatory" implies a vindictive motivation as part of a response. We will use the former term because it more accurately captures the meaning intended by Axelrod, which is the need for a response that is not motivated by any type of malice.
- 4 Another interesting parallel to our argument springs from Christian teaching on just war. War is quite obviously a form of noncooperation, and just war doctrine spells out the prerequisites that can justify a nation in engaging in such an extreme form of (provoked) noncooperation. While there is much disagreement in specific settings about the application of just war doctrine, there are some generally accepted standards that provide a starting point for analysis of whether a war is just. Interestingly, several of these just war requirements mirror the four traits to which Axelrod attributes the success

of tit-for-tat. A just war is legally and openly declared by a legitimate government (i.e., it is “clear”). A just war is conducted for a just cause, with self-defense being widely acknowledged as a just cause (i.e., a just war is “nice” and is “provoked”). A just war is conducted with a proper motive, such as restoring the peace, and the responsive force used is proportional to the force used by the aggressor (i.e., a just war is “forgiving”). For a brief statement of basic just war principles, see the Pew Forum’s website on just war (pewforum.org/just-war). For a thorough discussion of various issues relating to just war, see Ramsey (1968).

- 5 The Prisoner’s Dilemma gets its name from the most common story that is told about its origin. Two criminals, as the story goes, are caught in the midst of some mischief. They are separated at the jailhouse and interrogated. Each is told that if he confesses (defects), while offering up testimony against his accomplice, he will get a lighter jail sentence than his partner who will get the maximum penalty. The other strategy available to both prisoners is to not confess (cooperate) and not offer up incriminating testimony against the partner in crime. It is clear that both prisoners would prefer the all-cooperate outcome. However, incentives are such that if one cooperates while the other defects, the penalties will be severe. Both prisoners thus play defensively by choosing their dominant strategy to defect, and each is worse off from this all-defect outcome.
- 6 Axelrod (1997) acknowledges that the Prisoner’s Dilemma has become the “E. coli” of the social sciences, allowing a very large variety of studies to be undertaken in a common framework. Additionally, he writes, “the analytic and empirical findings about the Prisoner’s Dilemma from one field have often led to insights in other fields” (p.xi).
- 7 In order for cooperation to be maintained, the game must be played over and over with an unknown end, or theoretically equivalent, no end at all (i.e., played an infinite number of periods into the future). It is a well-known result that, if the dilemma is played a finite and known number of periods into the future, cooperation will theoretically break down immediately via backward induction. That is, in the last period of repeated play, there is no future with which to contend (and no penalty to worry about). Therefore, in the last period, each player would defect. But if each player defects in the last period, there is no reason to cooperate in the next-to-last period. This iterative notion of continued defection holds all the way back to the first period. Thus, a finite and known future is equivalent theoretically to a one-shot game.
- 8 Children are excellent examples of people who discount the future heavily. At least in our experience, telling a child to wait an hour for a reward is equivalent to asking the child to wait 10 years—they are one and the same.

24 FAITH & ECONOMICS

- 9 More technically, let $\rho = 1/(1+r)$ be the discount factor as function of the discount rate, r . Additionally, let C be the payoff from mutual cooperation, let D be the payoff from mutual defection, and let A be the one-time payoff from defection from the cooperative outcome, where $A > C > D$. Then cooperation will be maintained, if players are employing the grim strategy, when

$$\sum_{t=1}^{\infty} \rho^{t-1} C \geq A + \sum_{t=2}^{\infty} \rho^{t-1} D .$$

- It is well known that, where (as here) $0 < \rho < 1$, the infinite series $(1 + \rho + \rho^2 + \rho^3 + \dots) = 1/(1 - \rho)$. Thus, the above equation is equivalent to $C/(1-\rho) \geq A + \rho D/(1-\rho)$, which reduces to $\rho \geq (A-C)/(A-D)$. This formula defines the lowest value of ρ that will sustain a cooperative outcome in repeated play. In the Prisoner's Dilemma represented in Figure 1, $C = 3$, $D = 1$, and $A = 5$; thus $\rho \geq 0.5$ is the necessary and sufficient condition to maintain cooperation.
- 10 Axelrod (1997) states, "What the Prisoner's Dilemma captures so well is the tension between the advantages of selfishness in the short run versus the need to elicit cooperation from the other player to be successful in the longer run. The very simplicity of the Prisoner's Dilemma is highly valuable in helping us to discover and appreciate the deep consequences of the fundamental processes involved in dealing with this tension" (p. 5).
- 11 For example, such strategies can employ Markov models of the other player's behavior, and the use of Bayesian inference to determine the best choice of strategies given the history of the game.
- 12 Recall that the theoretical prediction in games of finite and known length is a total breakdown of cooperation. Interestingly, Axelrod mentions some odd end-game tactics employed by some entries, but most entries enjoyed some degree of cooperation at least once during the tournament, contrary to theory's prediction.
- 13 The second tournament was conducted just like the first, except an uncertain and probabilistic end to each game was specified to better conform to theory and to eliminate potential end-game strategies.
- 14 The tit-for-two-tats program was actually distributed to all of the participants of the first tournament as an example of a sample submission. No one submitted it.
- 15 Not surprisingly, Axelrod's *Evolution* sparked a surge of research that examines the robustness of tit-for-tat in environments that differ significantly from the basic Prisoner's Dilemma. For a discussion of this related research, see Axelrod (1997). Perhaps the most important innovation to the Dilemma's environment is the introduction of "noise," meaning that there exists some probability that a player's intended action will not be executed or received

correctly. That is, a player who intends to cooperate might, through noise, mistakenly defect or, equivalently, be perceived to defect. Interestingly, Nowak and Sigmund (1993) show that tit-for-tat can be exploited in such an environment by strategies that are responsive to observed outcomes (i.e., payoffs) rather than observed strategies (i.e., whether players cooperated or defected). However, tit-for-tat returns to its superior level of performance when it is modified to incorporate two additional traits (Wu and Axelrod, 1995): “generosity,” which allows some percentage of the other player’s defections to go unpunished, and “contrition,” which is being willing to cooperate in response to an opponent’s defection induced by one’s own accidental defection. Although we will not consider these additional characteristics in the next section, both concepts could easily be supported with scripture.

- 16 All biblical quotations are from the New International Version, unless otherwise noted.
- 17 Additional passages that contain explicit exhortations to be “nice” include Ps. 37:37b, Prov. 3:17, Prov. 17:28, Prov. 28:22, Prov. 29:4, and 1 Thes. 5:13b–15.
- 18 Indeed, the father may already have forgiven the younger son prior to the son’s return, since the father ran to meet the son while the son “was still a long way off” (Luke 15:20).
- 19 Other biblical passages that speak of forgiveness include Prov. 17:9, Prov. 17:14, Prov. 26:21, Matt. 6:14–15, and Matt. 18:21–35.
- 20 Seeing how Jesus spent a lot of time talking to pagans and tax collectors, the treatment He advocates may not be terribly severe. A few examples of Jesus’ interaction with pagans and tax collectors are Matt. 8:5–13 (the faith of the Roman centurion), Matt. 9:9–13 (the calling of Matthew the tax collector and dinner with tax collectors), and John 4:1–42 (the meeting with the Samaritan woman at the well).

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