A Model of Abstract Cooperation in Games of Uncertainty

Hillel J. Bavli

Southern Methodist University, Dedman School of Law

Author ORCID Identifier: https://orcid.org/0000-0003-4888-2842

A MODEL OF ABSTRACT COOPERATION IN GAMES OF UNCERTAINTY

*Hillel Bavli**

I. Introduction

Sir Ronald Fisher remarked that it was "Darwin's chief contribution, not only to Biology but to the whole of natural science, to have brought to light a process by which contingencies *a priori* improbable, are given, in the process of time, an increasing probability, until it is their non-occurrence rather than their occurrence which becomes highly improbable."[1] The idea that evolutionary processes naturally propel a state of affairs toward a higher, perhaps more complex or advanced, state of affairs is one that may extend to any context characterized by a dynamic time frame, including oligopoly models of repeated Prisoner's Dilemma.

I argue that, contrary to the popular assertion that coordinated pricing necessarily requires voluntary coordination,[2] oligopoly markets may evolve to a state of cooperation—one of collective profit maximization—absent a conscious state of coordination among the players, or even knowledge of such cooperation.

Professor Donald Turner, in his seminal treatise on the definition of "agreement" under the Sherman Act,[3] touches upon the idea that oligopoly may naturally precipitate parallel non-competitive pricing that may reasonably be considered individual conduct, but stops short of asserting that cooperative equilibria may result without any form of conscious commitment to coordinate prices. Turner argues that oligopoly markets are defined by their interdependent nature and that each player will rationally and naturally calculate the consequences of its price decisions with regard to the expected reactions of its competitors.[4] This explanation does not go far enough.

---

* J.D. candidate, 2006, Fordham University School of Law. Special thanks to my family and friends for their support, and to Professor Barry Hawk for his guidance and advice.

1. Bert James Lowenberg, *Darwin Scholarship of the Darwin Year*, 11 Am. Q. 526, 528 (Winter 1959) (quoting Julian Huxley, et al., eds., Evolution as a Process 91 (1954)).

2. *See infra* notes 102-06 and accompanying text.

3. Donald F. Turner, *The Definition of Agreement Under the Sherman Act: Conscious Parallelism and Refusals to Deal*, 75 Harv. L. Rev. 655, 655 (1962).

4. *See infra* notes 82-88 and accompanying text.

While it is true that cooperation is a natural consequence of the interdependent nature of oligopoly markets, it is not necessarily a result of conduct based on conscious regard of future reaction by competitors. While Turner proposes a theory of cooperation based on forward-looking consideration of future reaction, and similarly, George Stigler presents a theory of cooperation based on fear of detection and retaliation,[5] I propose a theory of evolution to cooperation based on the progression of consequences from previous actions.

Specifically, George Stigler "reasoned that 'oligopolists wish to collude to maximize joint profits' but 'if any member of any agreement can secretly violate it, he will gain larger profits than by conforming to it,' so a model of oligopoly should focus on the 'problem of policing a collusive agreement.'"[6]

Many economic and legal models determine a firm's ability to detect cheating by analyzing the quality and quantity of information exchanged among firms.[7] For example, industry trade associations are often accused of existing for the sole purpose of facilitating tacit collusion. Stigler's model goes a step further: it allows participants in a collusive arrangement to infer that a rival is secretly cutting prices, and defecting from the arrangement, if they unexpectedly lose many old customers or unexpectedly gain few new customers.[8]

This paper extends Stigler's model from a theory of tacit interaction and sustained collusion based on a player's ability to detect other players' defections to a theory of independent action based on a player's natural tendency to implement payoff-maximizing strategies by comparing previous performance to current performance and adjusting conduct accordingly. I propose that neither conscious coordination nor information exchange is necessary to achieve cooperative equilibria. Rather, an evolutionary process that parallels Darwinian biological evolution propels economic markets toward states of cooperative equilibrium.

---

5. *See infra* notes 18-21 and accompanying text.

6. Gregory J. Werden, *Economic Evidence on the Existence of Collusion: Reconciling Antitrust Law with Oligopoly Theory*, 71 ANTITRUST L.J. 719, 728 (2004) (quoting George J. Stigler, *A Theory of Oligopoly*, 72 J. POL. ECON. 44, 46 (1964)).

7. *See* STIGLER, *supra* note 6.

8. WERDEN, *supra* note 6, at 728.

II. When Collective and Individual Incentives Clash: An Introduction to the Prisoner's Dilemma

Imagine a situation in which a troublemaker is asked to report to the high school principal's office for investigation of his involvement in a prank. Earlier that morning, the student, Jim, along with one other student, John, released a chicken into the men's restroom. The principal sat the students in separate rooms and spoke to each individually. He informed Jim of the following: Jim, as well as John, was being investigated for pulling a prank earlier that morning, in which he had released a chicken in the men's restroom. Jim had been seen with John entering the men's bathroom during first period classes holding a large brown sack. Neither Jim nor John had followed school protocol, which required that they report to the school office to get a hall pass anytime they left class for any reason, even to use the restroom. For this infringement, the principal had authority to suspend the students for one month. For releasing the chicken in the restroom, the principal had authority to suspend them for eighteen months. The principal, however, lacked sufficient evidence to condemn Jim or John as the culprits of the chicken prank.

The principal asked that Jim testify regarding John's involvement in the prank. Jim's testimony would provide enough evidence to allow the principal to suspend John for 18 months, and in return, Jim would receive no punishment at all. If, however, John also testified against Jim, each student would be condemned to a twelve-month suspension (their respective eighteen-month suspensions would be downgraded to twelve-month suspensions as reward for their testimonies). If Jim refused to testify but John testified against Jim, Jim would receive an eighteen-month suspension and John would receive no punishment. Finally, if neither of the students testified against the other, the principal would have sufficient evidence only to suspend each of them for one month for failing to obtain a hall pass, but he would lack evidence to suspend them as the chicken prank culprits.

The foregoing example illustrates a well-known and much analyzed phenomenon dubbed the "Prisoner's Dilemma."[9] The Prisoner's Dilemma occurs when individual incentives and collective incentives clash. Assuming that Jim wished only to minimize the

---

9. Merrill Flood and Melvin Dresher invented the Prisoner's Dilemma game around 1950, and A. W. Tucker formalized the game shortly thereafter. Robert Axelrod, The Evolution of Cooperation 216 n.2 (1984).

severity of his own punishment,[10] and was indifferent to the severity of John's punishment, his optimal strategy was to testify against John regardless of whether he believed John would testify against him.[11] If John testified, Jim's optimal decision was to testify since a twelve-month suspension is less severe than an eighteen-month suspension. If John refused to testify, Jim's optimal decision was to testify anyway, since no punishment at all is less severe than a one-month suspension, and since Jim was indifferent to the severity of John's punishment.

Thus, the dilemma is clear: Jim and John, each strategizing individually and in their respective self-interests, would testify against each other and consequently each receive a twelve-month suspension. Had they, however, each strategized to minimize the aggregate severity of their respective punishments—had they "cooperated"—each refusing to testify against the other, they would have achieved the optimal collective outcome, a mere one-month suspension each.

The Prisoner's Dilemma is "common in everything from personal relations to international relations."[12] It applies to interactions between bacteria, individuals, nations, and corporations[13] and is the foundation of "many of the best-developed models of important political, social, and economic processes."[14] Oligopoly markets are characterized by interdependence among market suppliers ("firms"): each firm's profits are products of the decisions made by other firms in the market. Oligopoly market structures thus embody the elements of the Prisoner's Dilemma and are among the most examined of such contexts.[15]

Firms can maximize industry profits by behaving like a single monopolist and then dividing the profits among themselves.[16] The problem is that each firm has the temptation to cheat;[17] each firm *individually* maximizes its profit in any round of decision-making by expanding its output beyond the agreed-upon level (or, alterna-

10. Severity is presumably in proportion to length of suspension.

11. Remember, Jim and John are seated in separate rooms and are presumed unable to communicate.

12. AXELROD, *supra* note 9, at 27.

13. *Id.* at 28.

14. *Id.*

15. An oligopoly defines an economic market with few competitors such that production decisions affect the product's price. HAL R. VARIAN, INTERMEDIATE MICROECONOMICS: A MODERN APPROACH 468 (5th ed. 1999).

16. *Id.* at 483-84.

17. *Id.* at 484.

tively, by decreasing its price below the agreed-upon monopoly price).

Thus, once again, a dilemma unfolds: each firm, acting in its individual self-interest, chooses to overproduce (or underprice).[18] A competitive, profit-minimizing price emerges. Had the firms cooperated by foregoing the opportunity to overproduce (or undercut the others' prices), a monopolistic, profit-maximizing price would have surfaced.

The situations, or "games," described above are such that "players" each simultaneously make a single decision. Absent a mechanism of enforcing cooperation, the Prisoner's Dilemma holds true and the players forego the collectively optimal outcome. No player has reason to trust that the others will forego acting for the individual good for the sake of the collective good. A different outcome results, however, if the game is played repeatedly by the same players.[19]

"Repeated play allows players to respond to each other's actions, and so each player must consider the reactions of his opponents in making his decision."[20] Repeated play provides a critical enforcement mechanism: If a player cheats, or "defects" from a collusive arrangement in one period, the other players can "punish" him by defecting in future periods.[21] "In a repeated game, each player has the opportunity to establish a reputation for cooperation, and thereby encourage the other player to do the same."[22] The presumption, of course, is that players have the ability to detect when other players are cheating. Therefore, models of cooperation often focus on players' ability to detect defection.

III. GAME THEORY: A CONCISE REVIEW

Game theory is a "collection of tools for predicting outcomes[23] for a group of interacting agents, where an action of a single agent directly affects the payoffs (welfare or profits) of other participat-

18. A Cournot Model describes firms as choosing their quantities and allowing the market to determine the price. A Bertrand Model describes firms as setting their prices and allowing the market to determine the quantity sold. *Id.* at 482.

19. *Id.* at 498.

20. Drew Fudenberg & Eric Maskin, *The Folk Theorem in Repeated Games with Discounting and with Incomplete Information*, 54 ECONOMETRICA 533, 533 (1986).

21. VARIAN, *supra* note 15, at 498.

22. *Id.*

23. "Outcomes" refer to a list of actions adopted by each participant. OZ SHY, INDUSTRIAL ORGANIZATION: THEORY AND APPLICATIONS 11-12 (1995).

ing agents."[24] Game theory is particularly useful in situations where the number of players is small and the decisions of each player significantly affect the payoff of other players.[25] Thus, oligopoly markets, by reason of their interdependent nature, are ripe for game-theoretic analysis.[26]

A. Normal Form Games

A normal form game is one in which each player must make decisions without knowing what the other is doing.[27] Alternatively stated, each player moves simultaneously.[28] Consider the example described above, in which two high school students must choose, simultaneously and without knowing what the other will choose, whether to testify against the other.[29] In this example, there are four possible outcomes:[30] (Testify, Testify), (Testify, Don't Testify), (Don't Testify, Testify), (Don't Testify, Don't Testify). The various outcomes and respective payoffs are conveniently and conventionally displayed in matrix form.

		JOHN:			
		Testify		Don't Testify	
JIM:	Testify	−12	−12	0	−18
	Don't Testify	−18	0	−1	−1

The above table is a bimatrix[31] that describes each set of outcomes as well as the resulting payoffs that each player receives. By convention, the first payoff in each cell is that of the row player; the second payoff is that of the column player.[32] In this example, there is a "dominant strategy," one optimal strategy choice for each player regardless of the decision made by the other player.[33] Each player is best off choosing to testify, regardless of whether the other player testifies. The game's equilibrium, therefore, is the dominant strategy outcome (Testify, Testify).[34]

---

24. *Id.* at 11.
25. *Id.*
26. *Id.*
27. DOUGLAS G. BAIRD ET AL., GAME THEORY AND THE LAW 6 (1994).
28. SHY, *supra* note 23, at 12.
29. *See id.* at 6-9.
30. Remember, an "outcome" means a set of actions adopted by each player.
31. A bimatrix is a matrix in which each cell has two numbers. BAIRD ET AL., *supra* note 27, at 10.
32. *Id.*
33. VARIAN, *supra* note 15, at 493.
34. Not every game contains dominant strategy equilibria. *Id.* at 494.

A pair of strategies is said to be a "Nash Equilibrium" if each player's choice is optimal, given the other player's choice.[35] More formally, an outcome $\hat{a} = (\hat{a}^1, \hat{a}^2, \ldots, \hat{a}^N)$ (where $\hat{a}^i \in A^i$ for every $i = 1, 2, \ldots, N$) is a Nash Equilibrium if no player would find it beneficial to deviate, provided that all other players do not deviate from their strategies played at the Nash outcome.[36] For every player i, $i = 1, 2, \ldots, N$,

$$\pi^i(\hat{a}^i, \hat{a}^{-i}) \geq \pi^i(a^i, \hat{a}^{-i}) \text{ for every } \hat{a}^i \in A^i$$[37]

where π^i represents player i's payoff (welfare or profits). It should be noted that a dominant action equilibrium is also a Nash Equilibrium,[38] and further, that there can be multiple Nash Equilibria or no Nash Equilibria at all.[39]

B. Repeated Games

Up to this point, I have discussed one-shot games, i.e., games that consist of one period in which both players simultaneously choose their actions. Repeated games are simply one-shot games that are identically repeated.[40] As mentioned above, where cooperative equilibrium may fail in a one-shot game, it may emerge in a repeated game.[41] In the repeated game, as in the one-shot game, each player acts simultaneously during each round of play.[42] In the repeated game, however, it is assumed that all players can observe and monitor their own actions as well as those of all other players in all previous rounds. That is to say, they remember perfectly the game's "history."[43]

A game can be one of finite or infinite repetitions.[44] A finitely repeated game is one in which the number of periods, or rounds of play, is fixed.[45] An infinitely repeated game repeats indefinitely.[46] While the distinction may at first seem insignificant, particularly in games with many, yet finite, repetitions, it is often a critical factor in determining a game's outcome. Specifically, "backward induc-

35. *Id.*
36. SHY, *supra* note 23, at 18.
37. *Id.*
38. *Id.* at 19.
39. *Id.* at 19-20.
40. *Id.* at 28.
41. *Id.*
42. *Id.*
43. *Id.*
44. *Id.* at 29.
45. *See* VARIAN, *supra* note 15, at 498.
46. *Id.* at 498-99.

tion," a technique used to determine a game's equilibrium outcomes by seeking the Nash Equilibrium in the final round and working backwards to solve the Nash Equilibrium in each preceding round, is inapplicable to infinitely repeated games, since there is no final period.[47] The repeated prisoner's dilemma is the classic example: in games of fixed finite "horizon," or periods of play, the only equilibrium is one of both players defecting in every period, whereas a cooperative equilibrium is sustainable in games of infinite horizon.[48]

Whether an infinitely repeated game results in cooperative equilibrium depends, in part, on the players' "time discount factor."[49] The time discount factor represents a player's valuation of future payoffs relative to current payoffs. Specifically, the time discount factor is "the amount by which the value of a payoff in the next period must be adjusted to reflect its value in the present period."[50] Assuming that defecting from cooperation in one period will trigger punishment in future periods, cooperation is easier to sustain when players have higher time discount factors, since the threat of punishment in future rounds is stronger.[51]

C. The Folk Theorem, Player Strategies, and Nash Equilibria

Repeated games allow for outcomes that would not occur in one-shot games because players fear retaliation.[52] The "Folk Theorem" expresses this phenomenon.[53] It states that "any individually rational outcome can arise as a Nash equilibrium in infinitely repeated games with sufficiently little discounting."[54] The equilibria of an infinitely repeated game can, for example, be infinitely many sets of quantities between the "Cournot-Nash equilibrium" quantities—that is, the set of quantities such that each competitor is satisfied with its quantity given its rivals' quantities[55]—and the jointly payoff-maximizing quantities.[56] Game theory says little, however,

47. SHY, *supra* note 23, at 30.

48. FUDENBERG & MASKIN, *supra* note 20, at 534. Still, there is evidence that suggests cooperation in games with a large yet finite number of repetitions. *Id.* at 534-35 (providing a possible explanation of such results).

49. SHY, *supra* note 23, at 33.

50. BAIRD ET AL., *supra* note 27, at 168.

51. *See* SHY, *supra* note 23, at 31-33.

52. FUDENBERG & MASKING, *supra* note 20, at 533.

53. *Id.*

54. *Id.*

55. WERDEN, *supra* note 6, at 722.

56. *Id.* at 731.

about which equilibrium should result or how equilibrium is achieved.[57]

Economic literature has spawned a multitude of models exploring such questions.[58] Few economists dispute that retaliatory threat plays a significant role in attaining and maintaining cooperative equilibrium.[59] Economists have long sought after the most efficacious punishment strategies.[60] In quantity-setting games, it has been shown that the most effective enforcement scheme is to punish a defecting player as much as possible for one and only one period of the game.[61]

Another much-explored area concerns the ability of a player to detect defection. After all, effective enforcement of defection first requires its detection. The issue of uncertainty concerning other players' actions is thus an important strain of equilibrium analysis.[62] For example, if a player can only observe the market price, should the player interpret a price decline as another player's defection meriting punishment, or simply a decline in consumer demand?[63] It has been shown that if the market price falls sufficiently a player's optimal strategy is to infer defection, and therefore impose punishment.[64] Such models result in random price wars, since random fluctuations in demand may cause erroneous inferences of defection.[65]

Strategies in which defection triggers a retaliatory response have proved useful in the evolution of cooperation.[66] Indeed, the Tit-for-Tat strategy, a simple "policy of cooperating on the first move and then doing whatever the other player did on the previous

---

57. *Id.* at 731-32.

58. *Id.* at 732.

59. *See* Edward H. Chamberlin, *Duopoly: Value Where Sellers Are Few*, 44 Q.J. ECON. 63, 85 (1929); Stigler, *supra* note 6, at 44.

60. WERDEN, *supra* note 6, at 733.

61. *Id.* (citing Dilip Abreu, *On the Theory of Infinitely Repeated Games with Discounting*, 56 ECONOMETRICA 383, 384-86 (1988)); Dilip Abreu, *Extremal Equilibria of Oligopolistic Supergames*, 39 J. ECON. THEORY 191 (1986); CARL SHAPIRO, THEORIES OF OLIGOPOLY BEHAVIOR, *in* 1 HANDBOOK OF INDUS. ORG. 329, 366-70 (Richard Schmalensee & Robert D. Willig eds., 1989); STEPHEN MARTIN, ADVANCED INDUSTRIAL ECONOMICS 301-04 (2d ed. 2002)).

62. WERDEN, *supra* note 6, at 733.

63. *Id.*

64. *Id.* (citing Edward J. Green & Robert H. Porter, *Noncooperative Collusion under Imperfect Price Information*, 52 ECONOMETRICA 87, 89-94 (1984); Robert H. Porter, *Optimal Cartel Trigger Price Strategies*, 29 J. ECON. THEORY 313 (1983)).

65. WERDEN, *supra* note 6, at 733.

66. *Id.*

move,"[67] won numerous computer-run repeated Prisoner's Dilemma game tournaments in which many different strategies were matched against one another.[68]

IV. TACIT COLLUSION AND ANTITRUST LAW

Tacit collusion, in the context of antitrust law, refers to the phenomenon whereby "competing sellers might be able to coordinate their pricing without conspiring in the usual sense of the term—that is, without any overt or detectable acts of communication."[69] Section 1 of the Sherman Act prohibits "[e]very contract, combination . . . or conspiracy in restraint of trade."[70] These terms embrace the single concept of agreement.[71] "Section 1 reaches every arrangement in which multiple parties have a 'unity of purpose or a common design and understanding or a meeting of minds'[72]—every 'conscious commitment to a common scheme.' "[73]

Illegality under Section 1 of the Sherman Act is generally predicated upon the existence of an agreement.[74] But what exactly constitutes an agreement is a problem that has recurrently plagued antitrust law, and one to which the current analysis speaks.[75]

A. The Case against Condemnation of Tacit Collusion as a Section 1 Violation: The Interdependence Theory of Pricing

Professor Donald Turner argues that "oligopoly price behavior,"[76] or "conscious parallelism,"[77] can be expressed "as individual behavior—rational individual decision in the light of relevant economic facts"—rather than behavior based upon agreement.[78] "We could say that each seller has simply decided individually, perhaps after bitter experience, that it is more profitable not to indulge in

---

67. AXELROD, *supra* note 9, at 13.
68. WERDEN, *supra* note 6, at 733-34.
69. RICHARD A. POSNER, ANTITRUST LAW 52-53 (2d ed. 2001).
70. 15 U.S.C. § 1 (1994).
71. WERDEN, *supra* note 6, at 734 (citing PHILLIP E. AREEDA & HERBERT HOVENKAMP, ANTITRUST LAW ¶ 1400a, at 1 (2d ed. 2003)).
72. WERDEN, *supra* note 6, at 734 (citing Monsanto Co. v. Spray-Rite Serv. Corp., 465 U.S. 752, 768 (1984)).
73. WERDEN, *supra* note 6, at 734 (citing E. States Retail Lumber Dealers' Ass'n v. United States, 234 U.S. 600, 612 (1914)).
74. TURNER, *supra* note 3, at 655.
75. *Id.*
76. *Id.* at 666.
77. *Id.* at 663.
78. *Id.* at 666.

price competition under any but the most pressing circumstances, appealing as price cutting might appear to be from a less experienced viewpoint."[79]

Turner illustrates his point with the "salient facts" in *American Tobacco Co. v. United States*.[80] Three large cigarette companies, who together accounted for 90% of all cigarette sales, charged identical prices from 1928 to 1940, changing prices only seven times in that period.[81] Such price changes would be made by one company, to be followed almost immediately by the others, who would not sell further to dealers until their price changes were effected.[82]

Despite a general economic depression and declining costs, the three companies substantially raised their prices and thereby significantly increased profits.[83] Turner explains that such pricing behavior, "in the face of declining costs and weakening demand," is incontrovertibly "noncompetitive."[84] But no "economist worthy of the name" would conclude on the basis of these facts alone that such behavior is a result of an actual price agreement.[85] Rather, as economic theory suggests, the behavior is a natural result of an oligopoly market, in which parallel action may arise "without overt communication or agreement, but solely through a rational calculation by each seller of what the consequences of his price decision would be, taking into account the probable or virtually certain reactions of his competitors."[86] Alternatively stated, rational behavior, even independently rational behavior, militates against defection from the cooperative equilibrium, since any defection will, with virtual certainty, be met with retaliatory defections. Oligopolists base pricing decisions in part on anticipated reactions to such decisions; they are "interdependent" with respect to their pricing.[87]

Turner concludes that prohibiting companies from taking into account the probable reactions to their pricing decisions, forcing companies to ignore the interdependent nature of oligopolistic markets, would "demand such irrational behavior that full compli-

79. *Id.*
80. TURNER, *supra* note 3, at 661.
81. *Id.*; *see also* Am. Tobacco Co. v. United States, 328 U.S. 781, 805-08 (1946).
82. Turner, *supra* note 3, at 661.
83. *Id.*
84. *Id.*
85. *Id.*
86. *Id.*
87. POSNER, *supra* note 69, at 56.

ance would be virtually impossible."[88] Further, Turner argues that when real-world complications are present, the emergence of "a pattern of noncompetitive pricing . . . requires something which we could, not unreasonably, call a 'meeting of minds.'"[89]

B. The Case for Condemnation of Tacit Collusion as a Section 1 Violation

The requirement of agreement, according to Judge Richard Posner, does not exclude the possibility of a *tacit* agreement, and to confine the Sherman Act to cases involving explicit communication between parties is uneconomical and ill-aligned with the purposes of the Act.[90]

Posner argues that "there is no distortion of accepted meanings in viewing tacit collusion as a form of concerted rather than unilateral activity."[91] Courts do not distinguish between essentially linguistic forms of communication.[92] "A knowing wink can mean more than words."[93] To say that rivals may communicate by observing each others' marketplace actions does not greatly stretch the meaning of communication.[94] Posner argues that "[i]f seller *A* restricts his output in the expectation that *B* will do likewise, and *B* restricts his output in a like expectation, there is a literal meeting of the minds—a mutual understanding—even if there is no overt communication."[95] Posner asserts that such meeting of the minds constitutes an agreement within the meaning of the Sherman Act.[96]

Posner finds fault with courts' focus on conspiracy doctrine rather than on price theory. While the relevance of economic evidence to establishing price fixing plays an increasingly important role in courts, most courts hold that such evidence should be used only to help the trier of fact infer the existence of an overt agreement, and that such inference of conspiracy is indispensable to

---

88. TURNER, *supra* note 3, at 669.

89. WERDEN, *supra* note 6, at 772 (quoting TURNER, *supra* note 3, at 664).

90. POSNER, *supra* note 69, at 94.

91. *Id.* Turner and Posner are in agreement on this point. Turner does not brand tacit collusion as necessarily individual, rather than concerted, action. He maintains merely that neither point of view is unreasonable. He claims that oligopoly pricing behavior may be described as individual behavior "as well as it can be described as 'agreement.'" TURNER, *supra* note 3, at 666.

92. WERDEN, *supra* note 6, at 735.

93. *Id.* (quoting Esco Corp. v. United States, 340 F.2d 1000, 1007 (9th Cir. 1965)).

94. WERDEN, *supra* note 6, at 735 (emphasis added).

95. POSNER, *supra* note 69, at 94.

96. *See* American Tobacco Co. v. United States, 328 U.S. 781, 810 (1996).

finding a Sherman Act violation.[97] The problem is that not all price fixing activities actually cause a significant increase in price or reduction in output, and perhaps more serious, overt communication is not always necessary to significantly raise prices to collusive levels.[98] The law is thus at once under-inclusive and over-inclusive with respect to the Sherman Act's goals of pursuing economic efficiency.

Furthermore, Posner regards tacit collusion as the most harmful of all oligopoly conduct.[99] Exclusion of tacit collusion from the Sherman Act's ambit is paradoxical in that it fails to proscribe collusion where proscription is most necessary: in markets that are highly propitious to collusive equilibria.[100] It is situations in which collusion may be accomplished via market actions, rather than those which require overt communication, in which collusion will be most maintainable and probably most harmful.[101]

Posner proposes that oligopoly behavior be studied "in terms of the theory of cartels."[102] According to this view, oligopoly is necessary but not sufficient for successful price fixing.[103] Posner argues that coordinated pricing "is not an unconscious state."[104] Rather, "voluntary actions by the sellers are necessary to translate the bare condition of an oligopoly market into a situation of noncompetitive pricing."[105] Accordingly, such voluntary action, whether express or tacit, falls within Section 1 of the Sherman Act.[106]

C. Information Exchange and the Role it Plays in Maintaining Collusive Equilibria

George Stigler sought to reconcile the hypothesis that oligopolists wish to collude to maximize joint profits "with facts, such as that collusion is impossible for many firms and collusion is much

97. POSNER, supra note 69, at 93-94.

98. *Id.* at 53.

99. *Id.* at 55. *See also* Thomas A. Piraino, Jr., *Regulating Oligopoly Conduct under the Antitrust Laws*, 89 MINN. L. REV. 9, 31 (2004).

100. *Id.* (citing David L. Meyer, *The Seventh Circuit's High Fructose Corn Syrup Decision—Sweet for Plaintiffs, Sticky for Defendants*, ANTITRUST, Fall 2002, at 67, 71).

101. *Id.* at 30-31.

102. WERDEN, *supra* note 6, at 774 (quoting Richard A. Posner, *Oligopoly and the Antitrust Laws: A Suggested Approach*, 21 STAN. L. REV. 1562, 1569-75 (1969)).

103. Michael K. Vaska, *Conscious Parallelism and Price Fixing: Defining the Boundary*, 52 U. CHI. L. REV. 508, 514 (1985).

104. POSNER, *supra* note 69, at 97.

105. VASKA, *supra* note 103, at 514 (quoting POSNER, *supra* note 104, at 1575).

106. VASKA, *supra* note 103, at 514.

more effective in some circumstances than in others."[107] Stigler argues: "The reconciliation is found in the problem of policing a collusive agreement, which proves to be a problem in the theory of information."[108]

Antitrust law has developed a price-fixing rule that prosecutes and punishes "actual" agreements to fix price.[109] Market players, therefore, may take all the necessary steps to coordinate their pricing but stop short of any actual "agreement."[110] The most important of such steps is "the exchange of information as to what prices each seller is charging, or charged in the recent past, or intends to charge in the future."[111] Posner asserts that information-exchanges "foster collusive pricing both by enabling convergence on a single supracompetitive price and by facilitating detection of, and thereby discouraging, sales below that price."[112]

Thus, information exchange relates to collusive pricing as follows: As mentioned above, threat of retaliation holds collusion in tact. A credible threat requires the ability to enforce the collusive arrangement by punishing defection. Enforcement, in turn, requires detection of defections. Finally, as asserted by Stigler and Posner, information exchange is the mechanism by which detection is facilitated.

The problem is that unlike collusive pricing itself, information exchanges offer significant social benefits.[113] Generally, firms need market price information to make intelligent output decisions, and need competitor output and capacity plans to make intelligent decisions concerning their productive capacity.[114] Information exchange is necessary for the operation of an efficient market.[115] "Information is thus a two-edged sword: it is necessary if the competitive process is to work properly, but it can also facilitate collusion."[116]

107. STIGLER, *supra* note 6, at 44.
108. *Id.*
109. POSNER, *supra* note 69, at 159.
110. *Id.*
111. *Id.* at 159-60.
112. *Id.* at 160.
113. *Id.*
114. *Id.*
115. *Id.*
116. *Id.*

V. A Model of Evolution toward Cooperation

Assume, for the sake of simplicity, a non-stochastic duopoly market—a market with constant demand and only two players ($i = 1, 2$)—playing in a game of infinite repetitions ($t = 1, 2, 3, \ldots, \infty$). Further, assume vast information uncertainty: neither player has access to any information with regard to market conditions or to the other player. Each player has exclusive knowledge of its previous and present pricing as well as its previous and present profits, but neither player has knowledge concerning the other player's past, present, or future pricing decisions, the other player's cost function, profits, or even knowledge that the other player exists. Neither player knows whether he is the only player in the market, whether there are two players in the market, or whether there are numerous players in the market.

Each player strategizes as follows:

Where $a_{i,t}$ is Player i's action in period t, and A_i is the set of all of Player i's actions,

$$a_{i,t} \in A_i$$

$a_{i,t}$ is a function of Player i's payoff (profits) in round $t-1$, $\pi_{i,t-1}$, and Player i's predetermined probability of increasing price one unit (discussed further *infra*), Φ_i,

$$a_{i,t}(\pi_{i,t-1}, \Phi_i),$$ [117]

and Player i's payoff in period t, $\pi_{i,t}$, is a function of Player 1's action in period t, $a_{1,t}$, and Player 2's action in period t, $a_{2,t}$,

$$\pi_{i,t}(a_{1,t}, a_{2,t}).$$

1) In any given period, $t = 1, 2, \ldots, \infty$, there is a probability, Φ_i, that price will increase λ above the price in period $t-1$:

$$P(a_{i,t} = a_{i,t-1} + \lambda) = \Phi_i$$

2) Set price equal to α in period $t = 1$:

$$a_{i,1} = \alpha$$

3) In every period, t, set price, $a_{i,t}$, equal to the price in period $t-1$, $a_{i,t-1}$, unless either:

a. Price is increased to $a_{i,t-1} + \lambda$ by the probability function, Φ_i.

117. Remember, neither player's actions are direct functions of the other player's previous actions, since that information is unknown. The other player's actions will, however, cause indirect reactions since each player's profits are functions of all players' actions; in turn, actions are functions of profits.

b. Profits in period $t-1$, $\pi_{i,t-1}$, were less than profits in period $t-2$, $\pi_{i,t-2}$, and $t-3$, $\pi_{i,t-3}$.

$$\pi_{i,t-1} < \pi_{i,t-2} \text{ and } \pi_{i,t-1} < \pi_{i,t-3}$$

4) If 3b occurs, decrease price λ below the price in period $t-1$:

$$\text{If } \pi_{i,t-1} < \pi_{i,t-2} \text{ and } \pi_{i,t-1} < \pi_{i,t-3} \rightarrow a_{i,t} = a_{i,t-1} - \lambda.$$

5) In any given period, do not set price below α:

$$a_{i,t} \geq \alpha.$$

For the sake of simplicity, the strategy described above fails to calculate appropriate (real market) values of Φ_i, α, and λ. The model, nevertheless, suffices to indicate a possible tendency toward cooperative equilibrium in the absence of any conscious commitment to coordinate pricing.

Consider an outcome that may result from such a game, in which both players use the strategy described above, which I will refer to as the *Tester Strategy*. Assume $\Phi_i = 1/5$, $\alpha = 4$, and $\lambda = 1$. Further, assume the jointly profit-maximizing price, Ψ, to be eight.

Player 1	44445	44454	45444	44445	44445	55556	55655	56555	55565
Player 2	44544	45444	44544	44454	44445	56555	65555	55556	55655
Player 1	55556	66676	67666	66766	76666	66667	77778	77787	77877
Player 2	55556	67666	66676	66667	66676	66667	87777	78777	77787
Player 1	78777	77778	89888	98888	88988	88898	88889	88988	88898
Player 2	77877	77778	88898	89888	88889	88988	88889	88898	88889
Player 1	89888	89888	88898	88898	89888	88988	98888	88889	88988
Player 2	88898	88898	88898	88988	98888	98888	88898	88889	89888

Player 1's and Player 2's actions are respectively listed in the top and bottom rows of each box. Player-actions are listed in groups of five for clarity.

Each player sets price in $t = 1$ to $\alpha = 4$ pursuant to rule two. Since $\Phi_i = 1/5$, one of every five actions results in a price-increase of λ above the price in period $t-1$ pursuant to rule one.[118] In the period after such increase, Player i will maintain the elevated price, pursuant to rule three, unless profits during the elevated period

118. See the bimatrix above: Players both begin with a price of four. Each player effects a price elevation (in this instance, to five) one in every five actions (since the probability function, Φ_i, is equal to one-fifth). In the example provided, both players have equal probability functions. This, however, does not necessarily imply that they elevate price simultaneously—just that the probability of elevating their respective prices is equal. Thus, approximately once in every set of twenty-five actions the players' price elevations occur simultaneously. In the example provided, price is elevated simultaneously from four to five in the twenty-fifth period. Similarly, twenty-five periods again pass before price is elevated *simultaneously* from five to six, and so on and so forth.

decrease below profits in each of the two preceding periods. Note that Player i's price-elevation will cause profits to decrease below those of the two preceding periods unless the other player matches his elevation, in which case both players' profits will increase.[119]

Additionally, notice that the players strategize to lower price only if profits decrease below those of the *two* preceding periods, rather than that of only the *single* preceding period. Otherwise the players would engage in price wars every period after one player "tested" the market by raising price for one period and then returned to the preceding price if profits did not increase.[120] The disadvantage of such a strategy is that it may allow another player to exploit the somewhat forgiving strategy by defecting only once in succession.[121]

The success of the *Tester Strategy* depends on the conditions by which the market or game is defined. The game described above provides a setting ripe for *Tester Strategy* success. First, the market is defined as non-stochastic. Therefore, changes in profitability will correlate relatively well with changes in a competitor's action. Sec-

---

119. Take, for example, Player 1's first six actions. Player 1 begins by setting price at four (pursuant to rule two) and continues pricing at four until its profits decrease below its profits in the two preceding periods, or until the probability function takes effect (pursuant to rule three). In none of the first four periods are profits lower than they were in the two preceding periods. Therefore, Player 1 maintains a price of four until the fifth period, when the probability function elevates the price to five. Now, in period five, Player 1 profits less than it did in the two preceding periods (since Player 1 alone elevates its price in period five) and, therefore, lowers its price to four again in period six (pursuant to rule four). If, however, both prices are elevated to five simultaneously, as in period twenty-five, neither firm's profits decrease below those of the two preceding periods, and, therefore, both maintain the elevated price of five (again, pursuant to rule three).

120. Assume, for example, a strategy in which a profit-decrease below only the *single* preceding period triggers the return to a lower price, $a_{i,t-1} - \lambda$ (as opposed to the example described above where, in order to trigger a reduction in price, a profit-decrease below the *two* preceding periods is required). In period twenty-seven, where Player 2 alone raises its price from five to six, Player 1's profits increase while Player 2's profits decrease (since only Player 2 elevated its price). If Player 1's strategy only required profits to decrease below the *single* preceding period, Player 2's return to a price of five (pursuant to rule four), in period twenty-eight, would trigger a decrease in Player 1's price from five to four, since its profits were higher in the single preceding period, where Player 2, alone, elevated price. If both players implemented such a strategy, a price war would erupt and would continue until both players' pricing returned to $\alpha = 4$ (the lowest possible price, pursuant to rule five). *See* AXELROD, *supra* note 9, at 13.

121. Punishing defection may also be affected by the timing of the victim's price-elevation. The problem of such exploitation is to some extent alleviated by the conditions of vast uncertainty enumerated above. Conditions of greater certainty, however, may require further strategy elements that account for the possibility of such exploitation.

ond, the market is defined as a duopoly. Therefore, inappropriate "punishments" and, thus, the number of periods required to achieve "cooperation" are minimized.[122] Third, the game is defined by infinite repetitions. Therefore, players have an indefinite amount of time to establish a set of prices that maximizes profitability. Finally, the game is defined by vast information uncertainty. The *Tester Strategy*, which tests the market to elicit greater profits and react to changes in profits accordingly, is prone to converge toward a profit-maximizing price if provided with the opportunity to do so (the other player's strategy is "cooperative"), but will remain at a competitive price if not provided with the opportunity to raise prices (the other player's strategy is "uncooperative").

Use of the *Tester Strategy* by both players results in price-convergence toward the cooperative equilibrium. At equilibrium, both players price at eight, the joint profit-maximizing price, but each attempts to raise its price once in every five periods. A price increase above eight by one or both players will be maintained for that period alone, and price will return to the cooperative equilibrium, eight, in period $t + 1$. If one player alone raises price above eight, its profits will decrease as in any other period in which it alone raised its price. Similarly, if both players simultaneously raise prices, profits will decrease, since eight is the joint profit-maximizing price. In either case, the increase results in a return to the price in period $t-1$, the cooperative equilibrium, pursuant to rule four.

It is important to note that to achieve cooperative equilibrium it is necessary neither that players have similar cost structures nor that $\Phi_i = 1/5$, $\alpha = 4$, or that $\lambda = 1$. Such variables affect the equilibrium price as well as the number of periods required to reach such equilibrium. It does not, however, affect whether cooperative equilibrium is reached.[123]

In the case of $\Phi_i = 1/5$, for example, prices are increased by both players simultaneously, and thereby moved toward cooperative equilibrium once in twenty-five periods, whereas if $\Phi_i = 1/6$, prices

122. I hesitate to use the term "punishment," since players are not reacting directly to each other's actions. I use the term in order to maintain consistent usage of terminology. "Punishment" in this context simply refers to a decrease in one player's profits resulting from another player's price decrease below the established "cooperative" price. Similarly, terms as "cooperation" and "cooperative," in the context of such a model in which players do not directly observe each other's actions, refer to a state of affairs in which both players have pricing structures such that each player's profits increase as a result.

123. This assumes infinite repetitions and that Φ_i and λ are greater than zero.

would increase simultaneously, and thereby move toward cooperative equilibrium once in thirty-six periods.[124] Similarly, a greater λ moves prices toward cooperative equilibrium with greater speed. Also note that at cooperative equilibrium players may maintain different prices. This may occur, for example, if players have different cost structures.

VI. Limitations and Implications

The model described above contains many simplifying conditions. Turner may be correct in arguing that real-world conditions create complications for which emergence of "a pattern of non-competitive pricing . . . requires something which we could, not unreasonably, call a 'meeting of minds.'"[125] The model described is characterized by constant market demand and two market players. Such characterizations may not accurately simulate the vast majority of real-world markets. Relaxation of the conditions assumed by the model indeed may neither destroy the results nor invalidate its implications; it simply requires additional time to achieve equilibrium. However, real-world conditions change rapidly, and the model's assumption of infinite discrete repetitions may not adequately represent the time available in reality to reach cooperative equilibrium. Further, the model is quite sensitive to parameter modifications, and may call for computer simulations rather than the artificial simulations applied.

Its limitations notwithstanding, this model is useful in that it provides a framework by which cooperation may be viewed as resulting from independent action that falls outside the ambit of the Sherman Act's definition of "agreement."

Such a framework, however, does not necessarily imply that antitrust enforcement should be broadened or narrowed. A conclusion that cooperation may result absent conscious coordination can, in fact, be used as evidence for either argument.

It can be said that the effects of cooperation are equivalent regardless of whether players consciously coordinate such cooperation. It follows that the Sherman Act should, perhaps, extend its reach to situations of cooperation even absent any conscious coordination. I, however, argue to the contrary: a rule that proscribes pricing at cooperative equilibria even in the absence of any conscious coordination demands that firms act so irrationally by forc-

---

124. It is not necessary that $\Phi_1 = \Phi_2$.

125. Werden, *supra* note 6, at 772 (citing Turner, *supra* note 3, at 664).

ing them to deny themselves even independently profit-maximizing conduct that full compliance would be impossible in a capitalistic economy.

Capitalism is founded upon the principle that society's welfare is maximized when individuals and firms maintain the opportunity to maximize profitability. Of course, the right to maximize profits is far from absolute. Antitrust law must balance society's interest in maintaining markets in which firms are granted the opportunity to maximize profits and in protecting consumers from the negative effects of price-fixing. The Sherman Act wisely draws the line of illegality at the point where independent profit-maximization becomes collusive profit-maximization—that is, at the point where individual firms "agree" to collude. The model described above provides a framework in which defining "agreement" to include cooperation absent conscious coordination would force firms to ignore market conditions and profit-maximizing possibilities, and, as Turner noted, "demand such irrational behavior that full compliance would be virtually impossible."[126]

As noted, however, the model has limited applicability to real-world markets, and perhaps a "meeting of minds" is in fact necessary, in the real world, for achieving cooperation. The model is nevertheless a reminder that such equilibria are theoretically possible absent conscious coordination. It is, therefore, dangerous to stretch the definition of "agreement" beyond situations in which such coordination is evident.

VII. Conclusion

I proposed a model of evolution toward cooperation under conditions of vast uncertainty and in the absence of conscious price coordination and information exchange. A non-stochastic repeated Prisoner's Dilemma model was used to show that certain strategies may result in convergence toward cooperative equilibria without any agreement, or even possibility of agreement among the players. Rather, cooperation may evolve over time as a natural consequence of independent profit-maximizing conduct. The possibility of such convergence suggests that it may be inappropriate to extend the Sherman Act's definition of "agreement" beyond the ambit of conscious coordination.

126. Turner, *supra* note 3, at 669.