The elementary economics of social dilemmas

B. Curtis Eaton   *Department of Economics, University of Calgary*

Abstract. A social dilemma is, in essence, a prisoners' dilemma in a continuous strategy space. I discuss a number of social dilemmas that have caught my attention, offer an elementary, diagrammatic synthesis of them, and discuss some of the economic insights that the diagrams capture, including incentives for pre-commitment. Finally, I model pre-commitment via delegation and link results to the literature on the evolution of preferences.

L'économie élémentaire des dilemmes sociaux. Un dilemme social est essentiellement un dilemme du prisonnier dans un espace continu de stratégie. L'auteur discute d'un certain nombre de dilemmes sociaux qui ont retenu son attention, il en propose une synthése graphique élémentaire, et discute certaines des suggestions économiques qui découlent de ces diagrammes, comme par exemple les incitations à se pré-engager. Finalement, l'auteur construit un modèle de pré-engagement par délégation et relie ses résultats à la littérature sur l'évolution des références.

1. Introduction

Over the years I have seen models in a number of subdisciplines of economics, including macroeconomic and microeconomic theory, industrial organization, international economics, public economics, natural resources, and organization theory, that seemed to be variations on a small number of interrelated themes, and in this paper I want to offer an *elementary* synthesis of these models.[1] For

Canadian Journal of Economics / Revue canadienne d'Economique, Vol. 37, No. 4
November / novembre 2004. Printed in Canada / Imprimé au Canada

0008-4085 / 04 / 805–829 / © Canadian Economics Association

want of a better term, and for reasons that will be quite apparent, I call these models *social dilemmas*. Each of these social dilemmas fits into a very tidy and, I think, insightful taxonomy. I will lay out the taxonomy, discuss some of the social dilemmas that have captured the attention of economists, and develop some insightful diagrams. The synthesis is in the diagrams, and as many of you will quickly see, I am not the first person to construct many of them.

There is a close relationship between the social dilemmas explored here and the many prisoners' dilemmas that one finds in economics and related disciplines. In a social dilemma, the strategy space of any player is a continuum, whereas in a prisoners' dilemma, it typically has just two elements, and in this sense social dilemmas are dissimilar to prisoners' dilemmas. They are similar, however, in that a suitably chosen restriction of the strategy space in any social dilemma yields a prisoners' dilemma. In fact, many of the prisoners' dilemmas that one sees are created from an underlying social dilemma by cleverly choosing discrete strategies from the strategy space of the social dilemma. This is done, no doubt, to convey as simply and powerfully as possible the non-optimality of the non-cooperative equilibrium of the underlying social dilemma, but the simplicity comes at a cost, measured in insights lost, as I hope to show.

Interestingly, the very first formal social dilemmas that can be fitted into the taxonomy offered here come from Cournot's great book, first published in 1838 (Cournot 1960). In preparing for this address, I read Cournot's book for the first time, and I was struck by the extraordinary depth, clarity and breadth of his insight and analysis.

Cournot gets full credit for his model of oligopoly in which firms' strategies are quantities, but there is much more in this small book. For example, his analysis of competitive markets in chapter VIII is in some respects quite modern, and his contributions to game theory are, I think, more substantial than is generally appreciated. His analysis of the Cournot oligopoly model is elegant and quite general and includes a clever existence proof. In addition, he develops and analyses in depth another game theoretic model that captures a number of problems of interest to economists (including double marginalization and inefficient bribery of the sort analysed by Tullock 1980), and he provides an example of a game in which there is no equilibrium. To acknowledge Cournot's contributions to game theory, economists used to describe non-cooperative equilibria as Cournot-Nash, and I would like to suggest that we resurrect this nomenclature.

2. Social dilemmas

In this section I define *social dilemma*, lay out a taxonomy of social dilemmas, write down some tractable parametric dilemmas, develop a series of diagrams for various types of social dilemmas, and use the diagrams to articulate and explore properties of equilibrium and incentives for strategic pre-commitment.

2.1. A taxonomy

A social dilemma has $n \geq 2$ players, player i's strategy is denoted by x_i, and a strategy combination for the dilemma by $\mathbf{x} = (x_1, \ldots, x_n)$. Player i's strategy set is $\{x_i \mid x_i \geq 0\}$, and her payoff function is $F^i(x_1, x_2, \ldots, x_n)$, or more compactly, $F^i(\mathbf{x})$. Throughout I focus on stable, interior Cournot/Nash equilibria. In some neighbourhood of equilibrium, payoff functions are assumed to be strictly quasi-concave, twice differentiable, and to satisfy some sign restrictions on the partial derivatives of the payoff and the marginal payoff functions. Specifically, all of the cross partial derivatives of the payoff functions and the marginal payoff functions are assumed to have the same sign: for all i, all $j \neq i$, and all $\mathbf{x}$, it is assumed either that $F^i_j(\mathbf{x}) > 0$, or alternatively that $F^i_j(\mathbf{x}) < 0$; for all i, all $j \neq i$, and all $\mathbf{x}$, it is assumed either that $F^i_{ij}(\mathbf{x}) > 0$, or alternatively that $F^i_{ij}(\mathbf{x}) < 0$.

The restrictions on the *cross-effects* in the payoff and the marginal payoff functions yield a useful taxonomy. Following Bulow, Geanakopolos, and Klemperer (1985), a social dilemma is a game of *strategic complements* (SC) if the cross-effects in the marginal payoff functions are positive, and a game of *strategic substitutes* (SS) if they are negative; following Eaton and Eswaran (2002), a social dilemma is a game of *plain complements* (PC) if the cross-effects in the payoff functions are positive, and a game of *plain substitutes* (PS) if they are negative. The sign of the cross-effects in the marginal payoff functions determines the slope of the reaction functions, positive for SC dilemmas and negative for SS dilemmas, while the sign of the cross-effects in the payoff functions determine the shape of the iso-payoff contours.

A couple of parametric models are useful. The first is a *quadratic* model:

$$F^i(\mathbf{x}) = x_i \left(\alpha - \beta x_i + \gamma \sum_{j \neq i} x_j \right) \qquad \alpha > 0,\ \beta \geq |\gamma| > 0. \tag{1}$$

The second is a *log/linear* model:

$$F^i(\mathbf{x}) = \ln \left(\theta x_i + \phi \sum_{j \neq i} x_j \right) - \eta x_i \qquad \eta > 0,\ \theta \geq |\phi| > 0. \tag{2}$$

These forms have two very convenient properties. First, the associated reactions functions are linear in strategies: for the quadratic form

$$BR_i(\mathbf{x}_{-i}) = \frac{\alpha}{2\beta} + \frac{\gamma}{2\beta} \sum_{j \neq i} x_j, \tag{3}$$

and for the log/linear form

$$BR_i(\mathbf{x}_{-i}) = \frac{1}{\eta} - \frac{\phi}{\theta} \sum_{j \neq i} x_j, \tag{4}$$

where $\mathbf{x}_{-i}$ is the strategy vector $\mathbf{x}$ with player i's strategy, x_i, removed. Second, they readily yield social dilemmas in each cell of the taxonomy. A unique, stable, interior equilibrium is assured by the parameter restrictions in equations (1) and (2).

2.2. PS/SS dilemmas

For purposes of illustration, in the quadratic model, let us suppose that $n = 2$, and that $\gamma = -\beta < 0$. This model can be interpreted as a version of Cournot's model in which the players are firms and their strategies (quantities produced) are x_1 and x_2,[2] or as a one-period common access fishery in which the fishers' effort levels are x_1 and x_2.[3]

Notice that $F_j^i(x_1, x_2) = -\beta x_i < 0$, so the cross-effects in the payoff functions are negative, and this is a game of PS, and that $F_{ij}^i(x_1, x_2) = -\beta < 0$, so the cross-effects in the marginal payoff functions are also negative, and this is a game of SS.

The reaction functions, RF_1 and RF_2, the Cournot-Nash equilibrium of the game in which strategies are chosen simultaneously, E, and the iso-payoff contours through the equilibrium, IPC_1 and IPC_2, are pictured in figure 1. IPC_1 is necessarily horizontal where it intersects RF_1 – this is an implication of the fact that, given x_2, player 1's payoff is maximized on RF_1. Further, because this is a game of PS, IPC_1 has an inverted U-shape, and strategy combinations below the contour yield a larger payoff than do strategy combinations on the contour. Similarly, IPC_2 is necessarily vertical where it intersects RF_2, IPC_2 has a backward C-shape, and strategy combinations to the left of the contour yield a higher payoff than do strategy combinations on the contour.

Figure 1 yields a couple of undoubtedly familiar insights concerning the equilibrium of this PS social dilemma. First, the Cournot-Nash equilibrium is not Pareto-optimal; in fact, all of the strategy combinations in the shaded area southwest of the equilibrium Pareto-dominate it. Second, relative to the strategy combinations that Pareto-dominate it, equilibrium strategies are too large.[4]

Perhaps of more interest, figure 1 yields some insights into the incentive for strategic pre-commitment and the implications of such behaviour. Notice that player 1 could induce an equilibrium with higher payoff for itself if it could costlessly pre-commit to a more aggressive reaction function, one that shifted RF_1 to the right so that it intersected RF_2 at some point like S (for Stackelberg)

---

2 Let c be the firms' constant marginal cost, and let the inverse demand function be $(\alpha - c) - \beta(x_1 + x_2)$. Then the payoff function of player i is $x_i((\alpha - c) - \beta(x_1 + x_2)) - cx_i = x_i(\alpha - \beta(x_1 + x_2))$. This is, of course, just an illustration of Cournot's model. Cournot's analysis is quite general and quite sophisticated. Among other things, he provides a proof of the existence of an interior, stable equilibrium (Cournot 1960, 82).

3 Let the constant marginal cost of fishing effort be c. Assume that aggregate revenue as a function of aggregate effort, $X = x_1 + x_2$, is $R(X) = (\alpha - c)X - \beta X^2$, and suppose that fisher i's share of aggregate revenue is x_i/X. Then fisher i's payoff function is $(x_i/X)R(X) - cx_i = x_i(\alpha - \beta(x_1 + x_2))$.

4 When we talk about Pareto-optimality, the only actors whose payoffs are considered are the players in the game. Thus, in the Cournot illustration, we pay no attention to the welfare of the firms' customers.
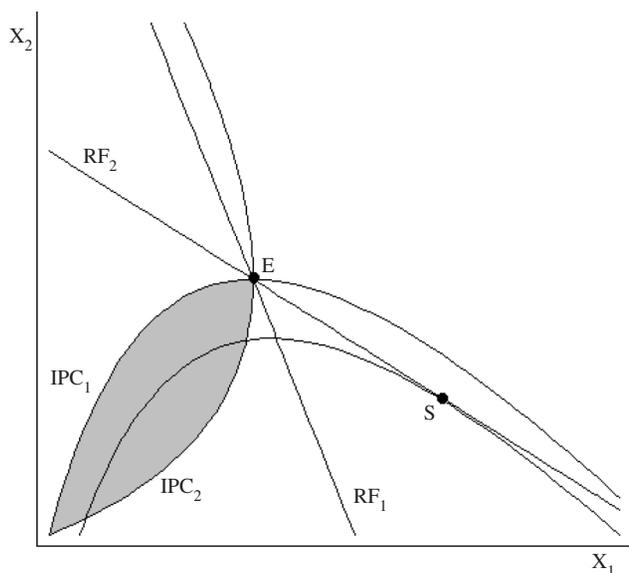
FIGURE 1   PS/SS dilemma

in the figure. Notice also that if firm 1 did shift its reaction function in the manner just described, player 2's equilibrium payoff would diminish. Conclusion: in PS/SS dilemmas, there is a *first-mover advantage*.

The ability to act on the incentives for strategic pre-commitment depends, naturally, on the properties of the real situation the model captures. If it is a common property fishery, strategies for shifting one's own reaction function include pre-commitment to technically superior, but uneconomic fishing gear that makes one a more aggressive competitor (the classic articles on common property fisheries are Gordon 1954 and Scott 1955). If it is a Cournot oligopoly, then one way of achieving the shift in RF_1 is for firm 1 to produce a carefully chosen larger quantity before firm 2 chooses its quantity, forcing an equilibrium at the intersection of 1's pre-committed quantity and 2's reaction function – this is, of course, the Stackelberg (1934) idea. Industrial organization economists explored a number of other pre-commitment strategies in the 1970s and 1980s. Strategies for shifting RF_1 include strategic inventory accumulation (Ware 1985), and pre-committing productive inputs so as to reduce variable costs thus shifting the firm's reaction function (Dixit 1980).

Figure 1 suggests another sort of strategic pre-commitment: player 1 could increase its payoff if it could costlessly pre-commit to some action that shifted player 2's reaction function, RF_2, downward. In the Cournot case, strategies for shifting the other firm's reaction function include the acquisition and hoarding of superior productive inputs, thereby raising the other firm's costs and shifting its reaction function in the desired manner (Salop and Scheffman 1983).

In some of the more interesting variations, the strategies for shifting reaction functions are not costless, and figure 1 cannot do justice to these variations, but it does very effectively capture the incentive that exists for firms to search for clever ways of positioning themselves before they play the game pictured in figure 1.

Finally, notice that if the firms simultaneously act on the strategic incentives inherent in this model, the equilibrium of the game will be northeast of the equilibrium pictured in figure 1, where both firms are worse off than they are in the absence of pre-commitment. In social dilemmas, even in the absence of strategic pre-commitment, the blind pursuit of self-interest dissipates some of the rent that is available, and when the players act on their strategic incentives they dissipate even more of it.

Brander and Spencer (1985) make these points very effectively in a seminal paper on strategic trade policy. They analyse a duopoly model in which firms situated in different countries compete in Cournot fashion in a market in some third country. First, they show that a government whose objective is to maximize welfare has an incentive to provide an export subsidy to its domestic firm – if the other government does nothing, the optimal export subsidy shifts the domestic firm's reaction function so that it intersects the foreign firm's reaction function at the Stackelberg equilibrium (S in figure 1). Then, they show that when both countries choose to subsidize exports, equilibrium welfare declines in both countries.

Most of this is, of course, old hat. It is of interest, I think, because the general insights apply to any two-player social dilemma in which strategies are PS/SS and the equilibrium is stable and interior. Interestingly, in addition to the Cournot and common access fishery illustrations, the quadratic model yields a number of other PS/SS dilemmas. A reinterpretation of the quadratic model with which we began this section ($n = 2$, $\gamma = -\beta$) captures the *double marginalization* problem that arises when a monopoly supplier of some product sells to a downstream retailer with market power.[5] If we suppose that $\gamma < 0$ and that $\beta > |\gamma|$, we get a PS/SS model that can be interpreted as a duopoly model in which the firms' strategies are quantities and the goods they produce are imperfect substitutes, as a duopoly model in which the firms' strategies are prices and the goods they sell are complements, or as model of production with negative externalities.[6] Clearly, there are many other social dilemmas of the PS/SS sort. Veblinian dilemmas, for example, are obviously PS, since each player's utility is a decreasing function of the quantity of the Veblen good acquired by other players, and depending on the details of the utility function, they may be SS or SC.

The insights concerning the properties of the Cournot-Nash equilibrium that we gleaned from figure 1 apply to all stable, interior equilibria of all social

---

5 Suppose, for convenience, that marginal costs of both firms are 0, interpret x_1 as the upstream firm's wholesale price and x_2 as the downstream firm's markup, and assume that the retail demand for the good is $\alpha - \beta(x_1 + x_2)$. Then firm i's payoff function is $x_i(\alpha - \beta(x_1 + x_2))$. If the upstream firm has the opportunity to choose its wholesale price first, then the equilibrium will be at S in figure 1.

6 The first two interpretations are straightforward, and for the third see footnote 9 below and suppose that $\gamma < 0$.

dilemmas of this type – strategy combinations southwest of the equilibrium Pareto-dominate the equilibrium. As we have emphasized, the ability to act on the incentives for strategic pre-commitment depends on the properties of the real situation the model captures, but the insights themselves are clearly applicable to all social dilemmas of the PS/SS type: players have an incentive to explore pre-commitments that either make them more aggressive competitors or make their competitors less aggressive; when pre-commitment is possible and attractive, there is a first mover advantage; when both players pre-commit, they both end up worse off than they are in the absence of pre-commitment.

2.3. PC/SC dilemmas

Now suppose that $n = 2$, and that $\beta > \gamma > 0$. This model can be interpreted as a Bertrand duopoly in which price setting firms sell goods that are imperfect substitutes[7], as a Cournot duopoly in which quantity setting firms sell goods that are complements[8], and as a model of production with a positive externality.[9] $F_j^i(x_1, x_2) = \gamma x_i > 0$, so this is a game of PC, and $F_{ij}^i(x_1, x_2) = \gamma > 0$, so this is a game of SC.

Figure 2 pictures the firms' reaction functions, the equilibrium of the simultaneous move game, and the iso-profit contours through the equilibrium for this dilemma. Player 1's iso-payoff contour is necessarily horizontal where it intersects RF_1, but, because this is a game of plain complements, 1's iso-payoff contour is U-shaped, and strategy combinations above the contour yield a larger payoff than do strategy combinations on the contour. Similarly, player 2's iso-payoff contour is necessarily vertical where it intersects RF_2, her iso-payoff contour is C-shaped, and strategy combinations to the right of the contour yield a larger payoff than do strategy combinations on the contour.

The equilibrium pictured in figure 2 is not Pareto-optimal, since strategy combinations in the shaded area northeast of the equilibrium Pareto-dominate the equilibrium. Notice, too, that, relative to the strategy combinations that Pareto-dominate it, the equilibrium strategies are too small.

Player 1 could induce a more attractive equilibrium if it could costlessly pre-commit to a reaction function that intersected RF_2 at some point like S.[10] If player 1 did shift its reaction function in this manner, player 2's equilibrium

---

7 Suppose that firm i's demand function is $a - \beta p_i + \gamma p_j$, and that the marginal cost for both firms is a constant, c. Then firm i's payoff function is $(p_i - c)(a - \beta p_i + \gamma p_j) = x_i(\alpha - \beta x_i + \gamma x_j)$, where $x_i \equiv p_i - c$ and $\alpha \equiv a - \beta c + \gamma c$. Given that $\gamma > 0$, these firms are producing goods that are substitutes, but not perfect substitutes as they are in the standard Bertrand (1988) model.

8 Let c be the constant marginal cost, and let i's inverse demand function be $(\alpha - c) - \beta x_i + \gamma x_j$. Then the payoff function of player i is $x_i((\alpha - c) - \beta x_i + \gamma x_j) - cx_i = x_i(\alpha - \beta x_i + \gamma x_j)$.

9 Interpret x_1 and x_2 as effort levels, and suppose that player j's effort level increases player i's productivity: specifically, assume that the revenue generated by player i's expenditure of effort is $x_i(a + \gamma x_j) - \beta x_i^2$, and that the marginal cost of effort is c. Player i's payoff function is then $x_i(a + \gamma x_j) - \beta x_i^2 - cx_i = x_i(\alpha - \beta x_i + \gamma x_j)$, where $\alpha \equiv a - c$.

10 In figures 2, 3, and 4, the point labelled S is a Stackelberg equilibrium. To keep the figures clean, I have not drawn the iso-payoff contour for player 1 that is tangent to RF_2 at S.
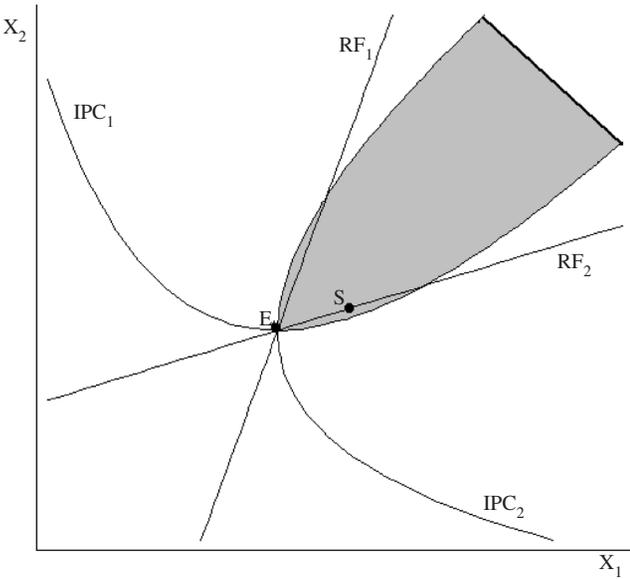
FIGURE 2   PC/SC dilemma

payoff would also increase. In fact, in this particular model player 2 gains more from 1's strategic pre-commitment than player 1 does, so if shifting one's own reaction function is the only interesting strategic move, there is a *second-mover* advantage in this model. This raises the interesting possibility that, in situations where players are able to pre-commit to strategies, each of them may choose not to do so, in the hope that the other will. Player 1 could also induce a more profitable equilibrium if it could costlessly shift player 2's reaction function upward. Finally, notice that if both players do pre-commit, both will be better off in the ensuing equilibrium than they are in the equilibrium identified in the figure. In the PC/SC case, and in contrast to the PS/SS case, strategic behaviour tends to ameliorate the rent dissipation that occurs in the original equilibrium. Without belabouring the point, it is perhaps worth mentioning that these insights are applicable to any interior equilibrium of any PC/SC social dilemma.

2.4. PC/SS dilemmas
Games in which individual players provide public or quasi-public goods nicely illustrate PC/SS games. Let x_i denote the quantity of the public good supplied by individual i. Clearly, when x_i increases, all other individuals are better off, so the game is PC. In addition, when x_i increases, for all individuals the marginal value of the public good decreases, so the game is SS. In the log/linear parametric form, suppose that $n = 2$, and that $\phi > 0$. Since $F_j^i(x_1, x_2) = \phi/(\theta x_1 + \phi x_2) > 0$, this is a PC game, and since $F_{ij}^i(x_1, x_2) = -\theta\phi/(\theta x_1 + \phi x_2)^2 < 0$, it is a SS game.
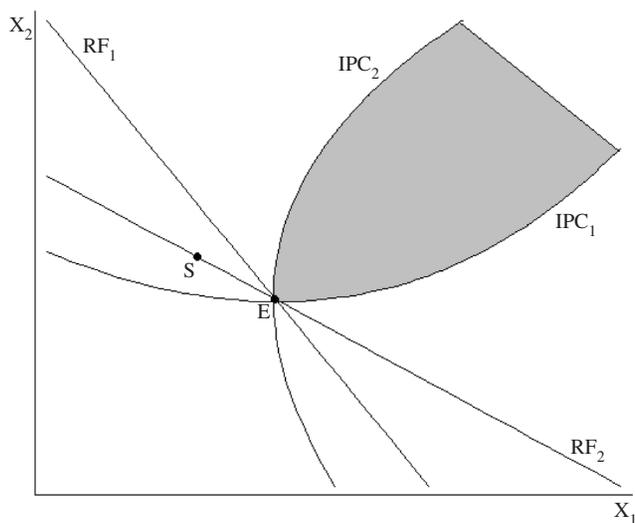
FIGURE 3   PC/SS dilemma

Think of the players as allied countries (such as the United States and Canada), x_i as country i's expenditure on *homeland security*, and $\ln (\theta x_i + \phi x_j)$ as the value (measured in dollars) to citizens of country i of security expenditures (x_1, x_2), and η as the price of a unit of x_i. The equilibrium of this PC/SS dilemma when strategies are chosen simultaneously is illustrated in figure 3. The insights that figure 3 yields concerning the properties of equilibrium of this dilemma are identical to those that figure 2 gave us – strategy combinations northeast of the equilibrium Pareto-dominate the equilibrium.

Figure 3 also yields some insights regarding strategic behaviour. Player 1 could induce a more attractive equilibrium if it could costlessly pre-commit to a reaction function that intersected RF_2 at some point like S, or if it could shift player 2's reaction function upward. Notice also that if player 1 did shift either reaction function in the manner described, player 2's equilibrium payoff would decrease. So, as there was in figure 1, there is a distinct first mover advantage in the PC/SS dilemma. Notice, also, that if both players act on their strategic incentives, they will be worse off in the ensuing equilibrium than they are in the equilibrium identified in the figure.

2.5. PS/SC dilemmas
The log/linear form also yields PS/SC dilemmas. As above, suppose that $n = 2$, and that the players are countries. In contrast to the previous model, suppose that the countries are enemies and hence that $\phi < 0$, that x_i is country i's expenditure on defence, and that $\ln (\theta x_i + \phi x_j)$ is the value (measured in dollars) to citizens of country i of defence expenditures (x_1, x_2), and that η is
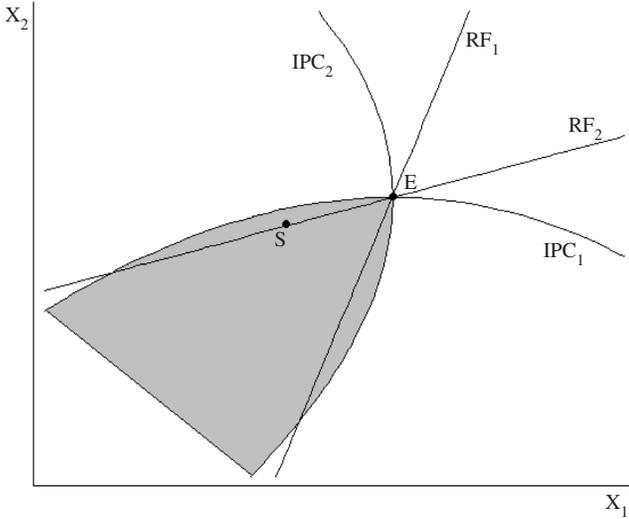
FIGURE 4   PS/SC dilemma

the price of a unit of x_i.[11] Since $\phi < 0$, the cross-effects in the payoff functions are now negative, which tells us that this is a PS dilemma, and the cross-effects in the marginal payoff functions are now positive, which tells us that this is an SC dilemma.

The Cournot-Nash equilibrium is illustrated in figure 4. Notice that the insights regarding the properties of equilibrium are identical to those we got from figure 1 – strategy combinations southwest of the equilibrium Pareto-dominate the equilibrium.

Country 1 could induce a more attractive equilibrium if it could costlessly shift RF_1 to the left so that it intersected RF_2 at some point like S, or if it could engineer a downward shift in Country 2's reaction function. If Country 1 did shift either reaction function in the manner described, Country 2's equilibrium payoff would also increase. In fact, if the only option is shifting one's own reaction function, in this particular model there is a *second mover* advantage, and depending on the circumstances, it is quite possible that both countries will hold back, hoping that the other will move first, even though either country could improve its position by pre-committing to a less aggressive stance. Finally, notice that if both countries do find a way to act on these strategic incentives, both will be better off in the ensuing equilibrium than they are in the equilibrium identified in the figure. In this case, strategic behaviour tends to ameliorate the profit dissipation that occurs in the original equilibrium.

---

11 When $\phi < 0$, we need to redefine the payoff function for strategy combinations such that $\theta x_i + \phi x_j < 0$. For any such strategy combination, $F^i(x_1, x_2) = -\infty$.

Remarkably, the first PS/SC dilemma in the literature is in Cournot (Cournot 1960). In chapter IX, Cournot analyses the pricing problem that arises when separate firms produce components that are, in the eyes of consumers, perfect complements. The firms choose prices to maximize profit, given that the demand for the final good is dependent on the sum of the prices of the components. Since the components are perfect complements, strategies are clearly plain substitutes. Further, as Cournot observed, depending on the curvature of the demand function, the reaction functions may be upward sloping (the SC case) or downward sloping (the SS case). It is worth noting that this Cournot pricing problem is isometric to the double marginalization problem discussed briefly above, and, as we observe below, it captures at least one other pricing problem that has been analysed in recent years. Perhaps we ought to call this the Cournot model of price competition. As an aside, it is worth noting that Cournot provides an illustration of this pricing problem for which there is no equilibrium (Cournot 1960, 104), another indication of his extraordinary sophistication.[12]

2.6. Many player social dilemmas

Many important social dilemmas of concern to economists involve more than two players, and it would be nice to have some simple diagrams that capture the essence of these many player social dilemmas. When payoff functions are *symmetric*, we can easily develop them.

First we need to define what we mean by symmetry of payoff functions. Consider any strategy combination, $\mathbf{x} = (x_1, x_2, \ldots, x_n)$. If we eliminate strategy x_i, we get a strategy vector of length $\mathbf{n} - 1$, $\mathbf{x}_{-i} = (x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_n)$. To define symmetry, we need notation for a vector of length $n - 1$, which we will call $\mathbf{x}_{-i}^{ra}$, in which the $n - 1$ strategies in $\mathbf{x}_{-i}$ are randomly assigned to the $n - 1$ slots in $\mathbf{x}_{-i}^{ra}$. Payoff functions $F^i(\mathbf{x})$, $i = 1, n$, are symmetric if they can be written as

$$F^i(\mathbf{x}) = F(x_i, \mathbf{x}_{-i}^{ra}) \quad \text{for all } \mathbf{x}_{-i}^{ra} \text{ and all } i. \tag{5}$$

The quadratic and the log/linear models are symmetric, because the influence that any other player's strategy has on player i's payoff works through the sum of the strategies of other players.

The convenient property of symmetric dilemmas is that they have a symmetric equilibrium. This means that we can characterize the symmetric equilibrium of such dilemmas by supposing that all players except the representative player, Rep, always use the same strategy. Let x_R be Rep's strategy, x_O the

---

12 Skaperdas (1992) develops an interesting model of production and appropriation in a world without property rights. Each player allocates one unit of a productive resource to two activities, production and appropriation (or conflict). The proportion of the total product that player 1 appropriates is $p(x_1, x_2)$, where x_1 and x_2 are resources allocated to appropriation by the two players. The proportion of the total product that player 2 appropriates is $p(x_2, x_1) = 1 - p(x_1, x_2)$, and the total amount produced is $C(1 - x_1, 1 - x_2)$. If we adopt the assumptions in Skaperdas and in addition assume that the production function is symmetric (that $C(1 - x_1, 1 - x_2) = C(1 - x_2, 1 - x_1)$), then one can show this game is PS/SC.
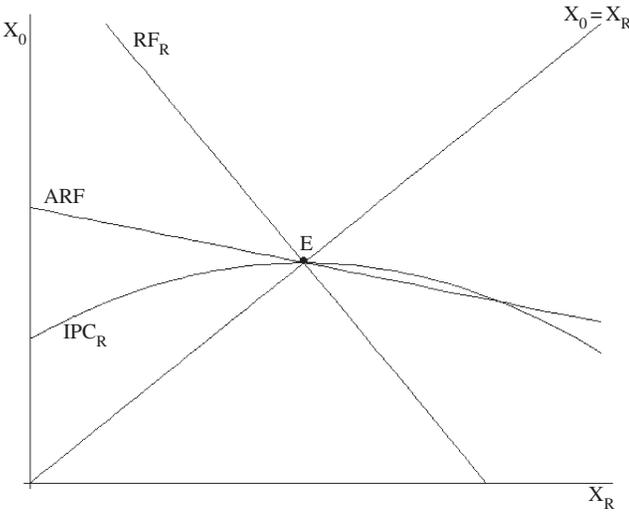
FIGURE 5   Many player PS/SS dilemma

common strategy of all other players, and $\mathbf{x}_{n-1}$ a vector of length $n-1$ in which each element is x_O. Then Rep's payoff function can be written as $F(x_R, \mathbf{x}_{n-1})$. Her reaction function in (x_R, x_O) space, RF_R, is implicitly defined by $F_1(x_R, \mathbf{x}_{n-1}) = 0$, the first-order condition for Rep's payoff maximization problem, given that all other players use strategy x_O. We can find the symmetric equilibrium of the game by intersecting RF_R with $x_O = x_R$ (see figure 5).

We can also find what we will call the *aggregate reaction function* for the other $n-1$ players in this game. If we fix x_R and allow the other $n-1$ players to choose their strategies, we have an $n-1$ player game that is also symmetric, and we can replicate what we did in the previous paragraph to find the symmetric equilibrium of this $n-1$ player game. The end result is a condition that implicitly defines the symmetric equilibrium strategy of the $n-1$ player game for every x_R. This is the their aggregate reaction function, ARF (see figure 5).

We will call the representative player in the $n-1$ player game *rep*, to distinguish her from Rep, and we will denote her strategy by x_r, to distinguish it from Rep's strategy, x_R. Let $\mathbf{x}_{n-2}$ denote a vector of length $n-2$ in which each element is x_O. Then, rep's payoff function can be written as $F(x_r, x_R, \mathbf{x}_{n-2})$. Her reaction function in the $n-1$ player game is implicitly defined by first-order condition $F_1(x_r, x_R, \mathbf{x}_{n-2}) = 0$. The symmetric equilibrium of the $n-1$ player game is found setting $x_r = x_O$ in this first-order condition. That is, $F_1(x_O, x_R, \mathbf{x}_{n-2}) = 0$ implicitly defines ARF.

The taxonomy of social dilemmas we defined above gives us four types of many-player social dilemmas. But as it turns out, the insights we get from the diagrams for these many-player social dilemmas parallel those we get

from the corresponding diagrams for the two-player social dilemmas. For this reason we develop just one illustration, a many-player dilemma that is PS/SS.

Imagine a situation in which entrepreneurs need to bribe n officials in order to set up their businesses, and let x_i denote the bribe demanded by official i. Assume that the number of entrepreneurs willing to pay the aggregate bribe, Σx_i, is $(\alpha - \beta \Sigma x_i)$. Then, the ith official's payoff function is $x_i(\alpha - \beta \Sigma x_j)$. This is, of course, the quadratic payoff function with $\gamma = \beta$. Notice that this also serves as a model of a transportation route with n independently operated toll booths,[13] as a Cournot oligopoly model with n firms, and as a one-period common property fishery. As is well known, as n increases without bound in this model, the aggregate payoff in equilibrium goes to zero.[14] In the Cournot interpretation this is socially desirable, but in the remaining cases it reflects complete rent dissipation.

In figure 5, we have drawn Rep's reaction function, RF_R, the aggregate reaction function of the other players, ARF, and Rep's iso-payoff contour through the equilibrium, IPC_R.[15] Symmetric strategies (that is, strategies on the line $x_O = x_R$) just southwest of the equilibrium Pareto-dominate the equilibrium, so the properties of equilibrium in this social dilemma parallel the properties of the equilibria in figures 1 and 4. Notice also that Rep has an incentive to find a way of committing herself to a more aggressive reaction function or of committing others players to less aggressive reaction functions, so the insights regarding strategic behaviour that come out of this diagram parallel those that we get from figure 1.

Nti (1997) exhaustively analyses an n player game of rent seeking and rent dissipation that is a generalization of Tullock's (1980) rent-seeking lottery. In the Nti game, x_i is the amount that player i spends to capture a prize of value V, the probability that she wins the prize is

$$P_i(\mathbf{x}) = \frac{h(x_i)}{r + \sum_{j=1,\, n} h(x_j)} \quad r \geq 0,\ h(0) = 0,\ h'(x_i) > 0,\ h''(x_i) > 0,$$

13 In an unpublished paper written in the late 1970s, David Donaldson developed a model of this sort to explain why traffic down the Rhine was snuffed out by the Nash behaviour of toll booth operators who owned successive segments of the river.

14 Interestingly, Cournot (1960) showed this result for both of his game theoretic models, in chapter VII for what we usually think of as the Cournot model, and in chapter IX for his model of price competition when firms produce components that are perfect complements in the eyes of consumers. Notice, also, that the competitive toll-setting interpretation in the text is, in fact, an illustration of the second Cournot model.

15 Rep's best-response function for this case is

$$BR_R(x_0) = \frac{\alpha}{2\beta} - \frac{(n-1)x_0}{2},$$

and ARF is

$$x_0 = \frac{\alpha}{n\beta} - \frac{x_R}{n}.$$

and her payoff function is $VP_i(\mathbf{x}) - x_i$. In the neighbourhood of the symmetric, interior equilibrium, this is a many player PS/SS dilemma.

3. Dilemmas in the economics literature

Most of the illustrations that I have used in this paper come from industrial organization, which reflects the fact that the heart of industrial organization is competition in which the number of players is small. I have focused on quantity and price competition, largely because these models came first in the economics literature, but other sorts of oligopolistic competition also turn out to be social dilemmas. For example, see Schmalensee (1976) and section 17.4 of Church and Ware (2000) on promotional competition; Brander and Spencer (1983) and D'Aspremont and Jacquemin (1988) on R&D competition in an oligopolistic settings; and Eaton and Eswaran (2002a) on choice of product durability in a duopoly setting.

International economics is, I believe, the other subdiscipline in which social dilemmas have long been at centre stage. Johnson (1953–4) on optimal tariffs is an early example – in fact, in discussing the optimal tariff issue in a review article on strategic aspects of trade policy, Dixit (1987) uses what is, in essence, figure 1 of this paper. Social dilemmas abound in the more recent literature on strategic trade policy. See, especially, Brander and Spencer (1985) and Eaton and Grossman (1986).

The recent literature on intellectual property rights in an international setting is another source of social dilemmas. Figure 3 of this paper is used to illustrate the equilibrium of a two-country patent game in Eaton, von Cayseele, and van Dijk (1994), Richardson and Gaisford (1996), and McCalman (2002). (See also Diwan and Rodrik 1991).

Public economics is also a rich source of social dilemmas. Dilemmas arising out of competition among interlinked jurisdictions in taxes and/or the provision of public goods have received considerable attention – see, for example, Mintz and Tulkins (1986), Wilson (1986), Wildasin (1988), and Bucovetsky (1991). Marceau (1997) analyses two versions of the social dilemma that arises when neighbouring jurisdictions compete in the effort to control crime, and either criminals or capital are mobile – figure 1 of this paper is used to illustrate the equilibrium of the crime deterrence equilibrium. In defence economics there is an extensive literature on international alliances, initiated by a paper by Olson and Zeckhauser (1966). One strand of the literature focuses on defence expenditures by allied countries, treating defence expenditures as a public good, and another strand analyses defense expenditures when countries are adversarial. Figure 3 plays a prominent role in the first strand and figure 4 in the second strand – see Sandler's (1993) excellent survey article.

The workhorse model of international environment pollution is a PS/SS dilemma. Polluter i's payoff function is $B_i(x_i) - D_i(\Sigma_{k=1}^{n} x_k)$. The benefit function B_i is assumed to be increasing and concave in its argument and the

damage function D_i to be increasing and convex in its argument. See, for example, Endres (1997) and Ulph (1998) on climate change and global warming, Endres and Finus (1999) on international environmental agreements, MiBfeldt (1998) on nuclear power, and Finus (2001) for some basic theory.

The literature on rent seeking and contests initiated by Lourey (1979) and Tullock (1980) is focused on a number of closely related social dilemmas. Nti (1997) is especially interesting. Closely related are a series of articles on the allocation of effort to production, theft, and defence in model economies with no property mights. See Eaton and White (1991), Skaperdas (1992), and Grossman and Kim (1995).

In a very influential paper that uses the framework set out in this paper, Cooper and John (1988) offer a synthesis of a number macroeconomic models. The focus is on coordination failures in Keynesian models, driven by strategic complementarities. Most of the models examined in the paper are social dilemmas in which strategies are plain and strategic complements, including macroeconomic models in which the coordination failure arises from technological complementarities in production, from trading externalities (as in Diamond 1982), and from demand externalities (as in Hart 1982 and Heller 1986).

4. Pre-commitment via preferences

One clever way of pre-committing to reaction functions involves strategically rigging the preferences of decision makers or, alternatively, choosing decision makers on the basis of their preferences, and in this section we briefly consider this sort of pre-commitment. We begin by thinking about the problem in a principal agent framework, and then we reinterpret results in an evolutionary context. For clarity, we restrict attention to two-player, symmetric social dilemmas, but the results can be generalized to many player, symmetric dilemmas. Since the game is symmetric we will use the notation for payoff functions developed in the previous section: player 1's payoff function is $F(x_1, x_2)$ and player 2's payoff function is $F(x_2, x_1)$.

4.1. Delegation, or choosing the agent's preferences

In this section we adapt the approach pioneered by Vickers (1985). (See also Sklivas 1987.) For clarity, we distinguish between the players and the decision makers in the social dilemma. We will call the players *principals* and their decision makers *agents*. Imagine an agent in a social dilemma whose preferences give weight, either positive or negative, to the payoff of the other principal. The agent will then choose her own strategy, x_i, to maximize a weighted sum of her principal's payoff and the payoff of the other principal. The following utility function captures this possibility:

$$U^i(x_1, x_2) = F(x_i, x_j) + a_i F(x_j, x_i), \tag{6}$$

where a_i is a parameter that captures the weight given to principal j's payoff in agent i's preferences. If $a_i > 0$, agent i could be described as *altruistic*, and if $a_i < 0$, she could be described as *misanthropic*.

Agent i's reaction function is characterized by the following first-order condition for her utility maximization problem: $F_1(x_i, x_j) + a_i F_2(x_j, x_i) = 0$. Totally differentiating the first-order condition with respect to x_i and a_i, we get

$$\frac{dx_i}{da_i} = \frac{F_2(x_i, x_j)}{-[F_{11}(x_i, x_j) + a_i F_{22}(x_j, x_i)]}. \tag{7}$$

Assuming that the usual second-order sufficient condition for agent i's utility maximization problem is satisfied, the denominator in the expression on the right is positive. Therefore, the sign of dx_i/da_i is the sign of $F_2(x_i, x_j)$, positive if strategies are PC and negative if they are PS. This, of course, implies that, relative to the case where $a_i = 0$, altruistic preferences increase agent i's best response in PC dilemmas and decrease her best response in PS dilemmas, while misanthropic preferences decrease agent i's best response in PC dilemmas and increase her best response in PS dilemmas.

These results, in combination with figures 1 through 4, dictate optimal agent preferences when just one principal, principal 1 for convenience, chooses her agent's preferences. In the PS/SS dilemma pictured in figure 1, principal 1 would like to shift her reaction function rightward, and this shift can be achieved by misanthropic preferences since the game is PS (i.e., since $F_2(x_i, x_j) < 0$). In the PC/SC dilemma pictured in figure 2, principal 1 would like to shift her reaction function rightward, and this shift can be achieved by altruistic preferences since the game is PC. In the PC/SS dilemma pictured in figure 3, principal 1 would like to shift her reaction function leftward, and this shift can be achieved by misanthropic preferences, since the game is PC. Finally, in the PS/SC dilemma pictured in figure 4, principal 1 would like to shift her reaction function leftward, and this shift can be achieved by altruistic preferences, since the game is PS. Notice that misanthropic preferences are optimal when strategies are SS, and altruistic preferences are optimal when strategies are SC.

Once again, the quadratic form readily yields some nice illustrations. When $n = 2$, if one principal, say principal 1, had the opportunity to move first, she would choose the Stackelberg strategy (equal to $[\alpha(2\beta + \gamma)]/[2(2\beta^2 - \gamma^2)]$). If, for some reason, she is not able to move first, the same result can be achieved by rigging her agent's preferences in just the right way: the weight that achieves this end, given that $a_2 = 0$, is $a^S = [\gamma(2\beta + \gamma)]/[2\beta(2\beta + \gamma) - \gamma^2]$. Notice that $a^S > 0$ if $\gamma > 0$, and $a^S < 0$ if $\gamma < 0$, and that $-1 < a^S < 1$. So, if one principal has the opportunity to rig her agent's preferences, her optimal agent is altruistic when strategies in the game are SC and is misanthropic when they are SS.

Clearly, both principals have an incentive to rig the preferences of their agents, and it is therefore of some interest to think about the subgame perfect equilibrium of a two-stage game in which principals choose preferences of their

agents, a_1 and a_2, in the first stage, and agents choose strategies, x_1 and x_2, in the second stage. In this two-stage game the principals will find their optimal preference parameters using backward induction. In stage two, given arbitrary preference parameters (a_1, a_2), agent i chooses x_i to maximize

$$U^i(x_1, x_2) = F(x_i, x_j) + a_i F(x_j, x_i), \quad i = 1, 2, j = 1, 2, j \neq i. \tag{8}$$

The equilibrium of the stage-two game can be conceptualized as $(x_1(a_1, a_2), x_2(a_1, a_2))$, since the equilibrium strategies are determined by the preferences of the agents. Then, in stage one, principal i solves the following maximization problem:

$$\max_{a_i} F(x_i(a_1, a_2), x_j(a_1, a_2)), \quad i = 1, 2. \tag{9}$$

The equilibrium of the stage-one game is a pair of preference parameters, (a_1^*, a_2^*), that satisfy the first-order conditions for these maximization problems. Since both the stage-one and stage-two games are symmetric, $a_1^* = a_2^* \equiv a^*$, and $x_1^* = x_2^* = x_1(a^*, a^*) \equiv x^*$.

For the quadratic form,

$$x_i(a_1, a_2) = \frac{\alpha(2\beta + \gamma(1 + a_i))}{4\beta^2 - \gamma^2(1 + a_1)(1 + a_2)},$$

$$a^* = \frac{\gamma}{2\beta - \gamma},$$

and

$$x^* = \frac{\alpha(2\beta - \gamma)}{4\beta(\beta - \gamma)}.$$

Notice that $a^* > 0$ if $\gamma > 0$, $a^* < 0$ if $\gamma < 0$, and $-1 < a^* < 1$. So, as above, optimal agents are altruistic when strategies are SC and are misanthropic when they are SS.

In Figure 6 we illustrate the equilibrium of the quadratic form when strategies are SC and PC, and optimal agents are therefore altruistic. RF_1^* and RF_2^* are the agent's reaction functions when their preferences are optimally chosen (that is, when $a_1 = a_2 = a^*$), and hence the point labeled E^* is the equilibrium of the two-stage game. By way of contrast, RF_1 and RF_2 are the agent's reaction functions when each agent simply maximizes her principal's payoff (that is, when $a_1 = a_2 = 0$), and hence the point labeled E is the equilibrium of the dilemma in which preferences are not cleverly rigged. We have also drawn principal 1's iso-payoff contour through E^*. Notice that the iso-payoff contour is U-shaped (because strategies are PC), is horizontal where it intersects RF_1 (because principal one's payoff is maximized on RF_1), and is tangent to RF_2^* at E^*. This tangency reflects the fact that (a^*, a^*) is the equilibrium of the stage 1 game in which a_1 and a_2 are chosen to maximize
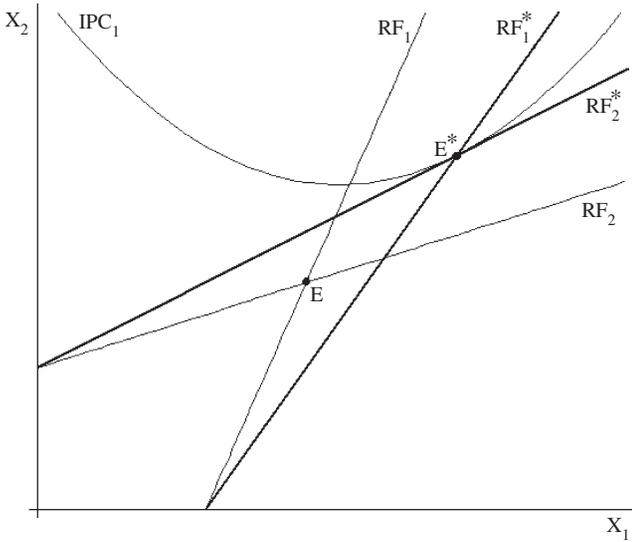
FIGURE 6   Rigged preferences, in a PC/SC dilemma

the principal's payoffs – if the iso-payoff contour intersected RF_2^*, $a_1 = a^*$ would not be a best response to $a_2 = a^*$ in the stage 1 game, contradicting the fact that (a^*, a^*) is the equilibrium of this game. Notice also that, since the game is symmetric and E lies below the iso-payoff contour through E^*, the principals are better-off when agents preferences are rigged than they are when they are not.

In Figure 7 we illustrate the equilibrium of the quadratic form when strategies are PS and SS, and optimal agents are therefore misanthropic. Notice that in this equilibrium, agents are more aggressive than they are when they simply maximize their principal's private payoff, and as a result their principals are worse off at E^* than at E. The tangency of principal 1's iso-payoff contour to RF_2^* at E^* is a necessary property of equilibrium, just as in figure 6. Figures 8 and 9 illustrate the equilibria of the preference rigging game when strategies are PC and SS (figure 8) and when they are PS and SC (figure 9).

4.2. An evolutionary interpretation

Consider for a moment the following metaphor for life. Life is a game in which, in every period, each person is paired with another who is randomly picked from a very large population of size N and given the opportunity to play a symmetric two-person social dilemma. The social dilemma that is played is the same from period to period, but the pairings themselves change over time. $F(x_i, x_j)$ is the contribution to players i's evolutionary fitness from one play of the game, when she is paired with player j. People have preferences of the sort described in equation (8), above, and preferences are passed from
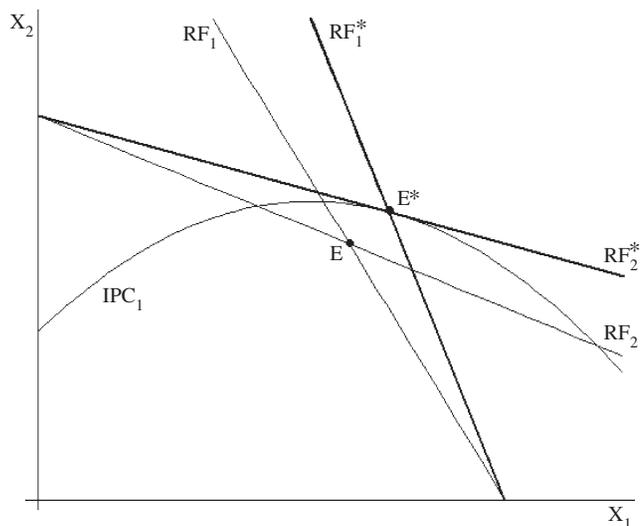
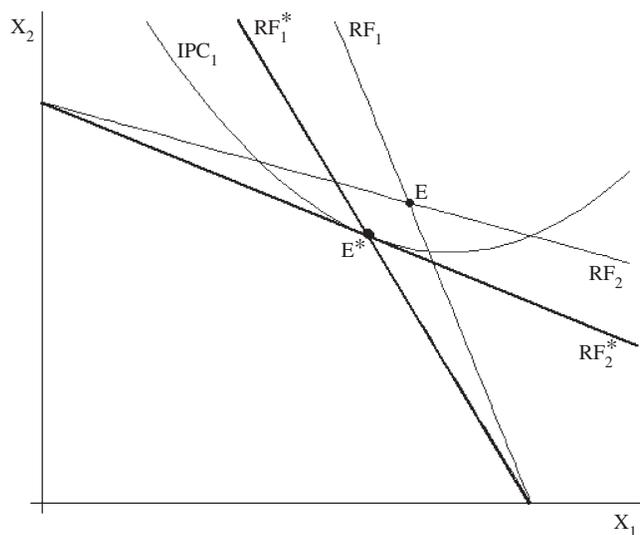FIGURE 7   Rigged preferences, in a PS/SS dilemma

FIGURE 8   Rigged preferences, in a PC/SS dilemma

parent to child with noise. In this imaginary world, it is natural to ask how preferences will evolve. Bester and Guth (1998), Bolle (2000), Possajennikov (2000), and Eaton and Eswaran (2003) have addressed this question in different settings.
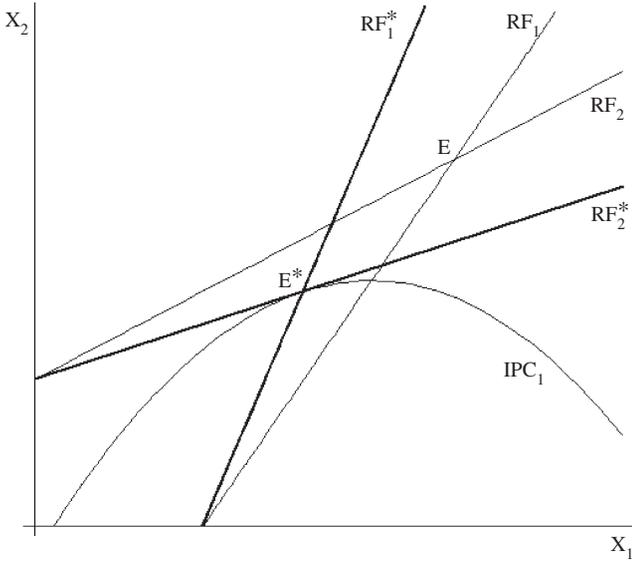
FIGURE 9   Rigged preferences, in a PS/SC dilemma

For reasons that will be obvious, we denote the *evolutionarily stable preference* parameter by a^*. It is defined by the property that when the preference parameters of all players except the mutant are equal to a^*, the mutant's relative fitness is maximized when her preference parameter is a^*.[16] So, suppose that $N - 1$ incumbents have preference parameter, a^*, and that a single mutant has a different preference parameter, $\hat{a}$. The expected fitness of the mutant is $F(x_1(\hat{a}, a^*), x_2(\hat{a}, a^*))$, since the mutant is always paired with an incumbent. On the other hand, the expected fitness of an incumbent is $[1/(N - 1)]F(x_1(a^*, \hat{a}), x_2(a^*, \hat{a})) + [1 - 1/(N - 1)]F(x_1(a^*, a^*), x_2(a^*, a^*))$ since the incumbent will be paired with the mutant with probability $1/(N - 1)$ and with another incumbent with probability $[1 - 1/(N - 1)]$. If we assume that the population is arbitrarily large, the incumbent's fitness is just $F(x_1(a^*, a^*), x_2(a^*, a^*))$. Now, consider maximizing the mutant's *relative* fitness:

$$\max_{\hat{a}} F(x_1(\hat{a}, a^*), x_2(\hat{a}, a^*)) - F(x_1(a^*, a^*), x_2(a^*, a^*)). \tag{10}$$

Clearly, the evolutionarily stable preference parameter, a^*, is the fixed point of the first-order condition for this maximization problem. Hence,

---

16 Here, I am using the notion of evolutionarily stable preferences laid out in Eaton and Eswaran (2003).

$$F_1(x_1(a^*, a^*), x_2(a^*, a^*)) \frac{\partial x_1(a^*, a^*)}{\partial \widehat{a}}$$

$$+ F_2(x_1(a^*, a^*), x_2(a^*, a^*)) \frac{\partial x_2(a^*, a^*)}{\partial \widehat{a}} = 0. \quad (11)$$

But this is also the first-order condition for the stage-one maximization problem considered above (problem 9). Hence, the evolutionary stable preference parameter is identical to the symmetric equilibrium preference parameter of the two-stage game considered above. In the evolutionary game, natural selection drives all preference parameters to a^*, and in the two-stage game the principals choose them, but the solutions are identical.

If we take the evolutionary story seriously, we see that when strategies in the social dilemma at the core of the evolutionary game are SC, then evolution yields players that are altruistic, and when they are SS, evolution yields players that are misanthropic. This is intriguing. It brings to mind stories about the enmity that is alleged to exist between rival CEO's (Robert Milton and Clive Beddoes, for example) and the affection that often exists between teammates.

If one expands the life metaphor a bit, some interesting possibilities for testing this approach to preferences come into focus. Think of life as a game in which, in every period, players are randomly assigned to play one of number of social dilemmas. In some of these strategies are SC, and in others they are SS. Imagine, too, that players have a preference parameter for each of the dilemmas. The evolutionary stable preferences parameters will be altruistic in SC dilemmas and misanthropic in SS dilemmas.

In this expanded metaphor for life, the environment has a number of niches that are, for analytical purposes, described by their ability to contribute to the fitness of the players who find themselves in them. Players are randomly assigned to niches over their lives, and through natural selection their preferences adapt to the niches. The view offered here suggests that we are programmed by nature to behave altruistically in some of life's niches and misanthropically in others.

The usual focus of game theorists is on evolutionarily stable *strategies*, as opposed to evolutionarily stable *preferences*. Of course, the evolutionarily stable strategies for the life metaphor discussed here are simply the Cournot/Nash equilibria of the dilemmas – the strategic considerations that drive evolutionary stable preferences play no role in evolutionary stable strategies. This suggests that it might be feasible to devise experiments that could test these approaches.

5. The insights

A short summary of the insights that come out of the analysis might be useful. The properties of Cournot-Nash equilibria depend upon whether strategies are PS or PC. Interior equilibria of social dilemmas are never Pareto-optimal; in

PC dilemmas the equilibrium is Pareto-dominated by strategy combinations northeast of the equilibrium; in PS dilemmas the equilibrium is Pareto-dominated by strategy combinations southwest of the equilibrium. This wisdom, of course, goes back a very long way in economics. There may nevertheless be some advantage to casting the wisdom in terms of the diagrams presented here.

The insights regarding the incentives for strategic behaviour are a little more subtle, and in summarizing them I will focus on incentives to rig one's own reaction function. In dilemmas in which strategies are SS, each player has an incentive to explore ways of pre-committing herself to a reaction function that is more aggressive in the sense that other players are made worse off by such pre-commitments. If the SS dilemma is PS, this means exploring ways of pre-committing to larger values of one's own strategy, and if it is PC, it means exploring ways of pre-committing to smaller values of one's own strategy, given the strategies of other players. If one player acts on this strategic incentive, the other players are made worse off, so there is a first-mover advantage in SS games. If all players simultaneously act on the incentive to pre-commit, they are all worse off.

In dilemmas in which strategies are SC, each player has an incentive to explore ways of pre-committing herself to a reaction function that is less aggressive in the sense that other players are made better off by such pre-commitments. If the SC dilemma is PC, this means exploring ways of pre-committing to larger values of one's own strategy, and if it is PS, it means exploring ways of pre-committing to smaller values of one's own strategy, given the strategies of other players. If one player acts on this strategic incentive, the other players are made better off, and this may result in a second-mover advantage. If all players simultaneously act on the incentive to pre-commit, they are all better off.

One general way of rigging reaction functions is for principals in social dilemmas to rig the preferences of their decision makers, or agents. If we restrict attention to agents who maximize a weighed sum of the payoffs of the principals, in SS dilemmas the optimal agent puts a negative weight on the payoffs of other principals, and in SC dilemmas the optimal agent puts a positive weight on the payoffs of other principals. In an evolutionary setting, the preferences of optimal agents can be interpreted as evolutionarily stable preferences.

References

Bertrand, J. (1988) 'Review of Walras's Theorie Mathematique de la Richesse Sociale and Cournot's Recherches Sur Les Principes Mathematiques De La Theorie Des Richesses,' in *Cournot Oligopoly: Characterization and Applications*, ed. A.F. Daugheety, (Cambridge, New York, and Melbourne: Cambridge University Press)

Bester, H., and W. Guth (1998) 'Is altruism evolutionarily stable?' *Journal of Economic Behavior and Organization* 34, 193–209

Bolle, F. (2000) 'Is altruism evolutionarily stable? And envy and malevolence? Remarks on Bester and Guth,' *Journal of Economic Behavior and Organization* 42, 131–3

Brander, J.A., and B.J. Spencer (1983) 'Strategic commitment with R and D: the symmetric case,' *Bell Journal of Economics* 14, 225–35

— (1985) 'Export subsidies and international market share rivalry,' *Journal of International Economics* 18, 83–100

Bucovetsky, S. (1991) 'Asymmetric tax competition,' *Journal of Urban Economics* 30, 167–81

Bulow, J.I., J.D. Geanakoplos, and P.D. Klemperer (1985) 'Multimarket oligopoly: strategic substitutes and complements,' *Journal of Political Economy* 93, 488–511

Church, J.R., and R. Ware, (2000) *Industrial Organization: A Strategic Approach* (New York: McGraw-Hill)

Cooper, R., and A. John (1988) 'Coordinating coordination failures in Keynesian models' *Quarterly Journal of Economics* 103, 441–63

Cournot, A.A. (1960) *Researches into the Mathematical Principles of the Theory of Wealth* (Fairfield, NJ: Augustus M. Kelley)

d'Aspremont, C., and A. Jacquemin (1988) 'Cooperative and noncooperative R and D in duopoly with spillovers,' *American Economic Review* 78, 1133–7

Diamond, P.A. (1982) 'Aggregate demand management in search equilibrium,' *Journal of Political Economy* 90, 881–94

Diwan, I., and D. Rodrik (1991) 'Patents, appropriate technology, and north-south trade,' *Journal of International Economics* 30, 27–47

Dixit, A.K. (1980) 'The role of investment in entry-deterrence,' *Economic Journal* 90, 95–106

— (1987) 'Strategic aspects of trade policy,' in *Advances in Economic Theory: Fifth World Congress* (Cambridge, New York, and Melbourne: Cambridge University Press)

Eaton, B.C., and M. Eswaran (2002a) 'Asymmetric equilibria and strategic behaviour in oligopolistic markets,' in *Applied Microeconomic Theory* (Cheltenham, UK: Edward Elgar)

— (2002b) 'Noncooperative equilibria in one-shot games: a synthesis,' in *Applied Microeconomic Theory* (Cheltenham, UK: Edward Elgar)

— (2003) 'The evolution of preferences and competition: a rationalization of Veblen's theory of invidious comparisons,' *Canadian Journal of Economics* 36, 832–59

Eaton, B.C., and W.D. White (1991) 'The distribution of wealth and the efficiency of institutions,' *Economic Inquiry* 29, 336–50

Eaton, B.C., P. van Cayseele, and T. van Dijk (1994) 'An address model of patent breadth with two countries,' in *The Limits of Patent Protection* (Maastrich, Holland: Maastrich University Press)

Eaton, J., and G.M. Grossman (1986) 'Optimal trade and industrial policy under oligopoly,' *Quarterly Journal of Economics* 101, 383–406

Endres, A. (1997) 'Negotiating a climate convention: the role of prices and quantities,' *International Review of Law and Economics* 17, 147–56

Endres, A., and M. Finus (1999) 'International environmental agreements: how the policy instrument affects equilibrium emissions and welfare,' *Journal of Institutional and Theoretical Economics* 155, 527–50

Finus, M. (2001) *Game Theory and International Environmental Cooperation* (Northampton, MA: Edward Elgar)

Gordon, H.S. (1954) 'The economic theory of a common-property resource: the fishery,' *Journal of Political Economy* 62, 124–42

Grossman, H.I., and M. Kim (1995) 'Swords or plowshares? A theory of the security of claims to property,' *Journal of Political Economy* 103, 1275–88

Hart, O. (1982) 'A model of imperfect competition with Keynesian features,' *Quarterly Journal of Economics* 97, 109–38

Heller, W.P. (1986) 'Coordination failure under complete markets with applications to effective demand,' in *Equilibrium Analysis Essays in Honor of Kenneth J. Arrow*, Vol. 2 (Cambridge, New York, and Sydney: Cambridge University Press)

Johnson, H.G. (1953–4) 'Optimum tariffs and retaliation,' *Review of Economic Studies* 21, 193–4

Loury, G.C. (1979) 'Market structure and innovation,' *Quarterly Journal of Economics* 93, 395–410

Marceau, N. (1997) 'Competition in crime deterrence,' *Canadian Journal of Economics* 30, 844–54

McCalman, P. (2002) 'National patents, innovation and international agreements,' *Journal of International Trade and Economic Development* 11, 1–14

MiBfeldt, F. (1998) 'Nuclear power games,' in *Game Theory and the Environment* ed. N. Hanley and H. Folmer (Cheltenham, U.K., and Northampton, MA: Edward Elgar)

Mintz, J., and H. Tulkens (1986) 'Commodity tax competition between member states of a federation: equilibrium and efficiency,' *Journal of Public Economics* 29, 133–72

Nti, K.O. (1997) 'Comparative statics of contests and rent-seeking games,' *International Economic Review* 22, 43–59

Olson, M., and R. Zeckhauser (1966) 'An economic theory of alliances,' *Review of Economics and Statistics* 48, 266–79

Possajennikov, A. (2000) 'On the evolutionary stability of altruistic and spiteful preferences,' *Journal of Economic Behavior and Organization* 42, 125–9

Richardson, R.S., and J.D. Gaisford (1996) 'North-south disputes over the protection of intellectual property,' *Canadian Journal of Economics* 29, 81

Salop, S.C., and D.T. Scheffman (1983) 'Raising rivals' costs,' *American Economic Review* 73, 267–71

Sandler, T. (1993) 'The economic theory of alliances: a survey,' *The Journal of Conflict Resolution* 37, 446–83

Schmalensee, R. (1976) 'A model of promotional competition in oligopoly,' *Review of Economic Studies* 43, 493–507

Scott, A. (1955) 'The fishery: the objectives of sole ownership,' *The Journal of Political Economy* 63, 116–24

Skaperdas, S. (1992) 'Cooperation, conflict, and power in the absence of property rights,' *American Economic Review* 82, 720–39

Sklivas, S.D. (1987) 'The strategic choice of managerial incentives,' *RAND Journal of Economics* 18, 452–8

Tullock, G. (1980) 'Efficient rent seeking,' in *Toward a Theory of the Rent Seeking Society*, ed. J.M. Buchanan, R.D. Tollison, and G. Tullock (College Station, TX: Texas A and M University Press)

Ulph, A. (1998) 'Learning about global warming,' in *Game Theory and the Environment* (Cheltenham, U.K., and Northampton, MA: Edward Elgar)

van Dijk, T. (1996) 'Patent height and competition in product improvements,' *Journal of Industrial Economics* 44, 151–67

Vickers, J. (1985) 'Delegation and the theory of the firm,' *Economic Journal* 95, 138–47

von Stackelberg, H. (1934) *Marktform and Gleichgewicht* (Vienna: Julius Springer)

Ware, R. (1985) 'Inventory holding as a strategic weapon to deter entry,' *Economica* 52, 93–101

Wildasin, D.E. (1988) 'Nash equilibria in models of fiscal competition,' *Journal of Public Economics* 35, 229–40

— (1991) 'Some rudimentary "duopolity" theory,' *Regional Science and Urban Economics* 21, 393–421

Wilson, J.D. (1986) 'A theory of interregional tax competition,' *Journal of Urban Economics* 19, 296–315