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The GATT Negotiations and US/EC Agricultural Policies: Solutions to Noncooperative Games

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Abstract

Countries cooperate in negotiating treaties. However, treaty compliance is noncooperative; signatories comply with treaties only if compliance leaves them better off than noncompliance. US and EC agricultural policies of 1986 are modeled through a noncooperative game. Bilateral treaties, formalizations of Nash Equilibria, are presented which improve US and EC welfare.

In 1987 the Reagan administration proposed the complete liberalization of trade in agricultural commodities in ten years at the General Agreement on Tariffs and Trade (GATT) negotiations in Geneva, Switzerland. This proposal encountered great resistance from many countries, most notably the countries of the European Community (EC). Despite this resistance, the EC and others admitted that current agricultural policies were too expensive and destabilized world markets in agricultural products, but the disparate proposals offered by each negotiating block, the United States (US), the EC, the Cairns group, and the Nordic countries, indicated that much compromise was necessary before any agreement could be reached (National Center) and a treaty signed.

Because the signatories of treaties are sovereign states none can be compelled to sign a treaty or comply with it after it is signed. Compliance depends on whether countries are made better off with the treaty than without it, thus noncooperative game theory is an ideal tool to evaluate treaties. Using three noncooperative games between the US and the EC based on an empirical trade model by Mahe and Tavera, this paper explores two kinds of treaties. One assumes the treaty enables the US and the EC simultaneously to introduce a new policy instrument which political powers at home would otherwise exclude. The second treaty formalizes Nash equilibrium strategies in an infinitely repeated game. In both cases the US and the EC are better off when complying with the treaty.

Many authors have applied game theory to world grain markets, for example Sarris and Freebairn, Karp and McCalla, and Paarlberg and Abbot. They assume governments have preferences over domestic groups in the market and play a noncooperative game choosing policies to maximize their preferences taking the policies of other governments as given. This defines a Nash (or Cournot-Nash) equilibrium for the game. The equilibrium implicitly determines world prices, price stability, and trade flows. The following games use Nash equilibrium as a solution concept.

Game One

The action spaces of each player, the US and the EC, contain four policy alternatives. Option 0 is the status quo, what was observed in 1986. Option 1 changes policy in grains and feed. Option 2 contains option 1 and policy changes in beef and dairy. Option 3 contains option 2 and policy changes in sugar. As a rule, the policy changes reflect greater and greater liberalization in agricultural trade. See Mahe and Tavera (p. 10) for a more explicit description of these four policies. Player i's action space, i = us, ec, is defined as

$$A_i = \{0, 1, 2, 3\}.$$

Let a_i be a generic element of A_i and the Cartesian product of the two action spaces, $A = A_{us} \times A_{ec}$, be the action space for the game. For simplicity adopt the convention that -i denotes the other player.

Each government considers three constituencies when formulating policy: producers, consumers, and all others. The welfare of producers is measured by their value added (P). The consumers' welfare is measured through consumer surplus (C). The welfare of all others is given by the surplus or deficit of the agricultural budget (B). P, C, and B are functions of A. Of course governments must be able to compare the welfares of each constituency to decide which policy option is best. Thus let each government have an additive social welfare function.

$$(1)\ V_i(A) = W_{ci}C_i(A) + W_{bi}B_i(A) + W_{pi}P_i(A);\ i = us, ec;$$

where $W_{ji} \geq 0$, j = c, b, p. Since we are only interested in the ordinal properties of this function and since the function is additive, we normalize V_i setting $V_i(0,0)$ to zero and W_{pi} to one. Mahe and Tavera (p. 20) provide explicit values for $C_i(A)$, $B_i(A)$, and $P_i(A)$.

To define a Nash equilibrium for this game, a_i^*, i = us, ec, is a <u>best response</u> to a_{-i} if $V_i(a_i^*, a_{-i}) \geq V_i(a_i, a_{-i})$ for all a_i in A_i. A pair, (a_{us}^*, a_{ec}^*), is a <u>Nash equilibrium</u> if a_{us}^* (resp. a_{ec}^*) is best response to a_{ec}^* (resp. a_{us}^*).

Although players are maximizers in playing Nash equilibrium strategies, those actions are not always optimal. The "prisoner's dilemma" is the most conspicuous example of this. Furthermore games may have multiple Nash equilibria. Under suitable conditions treaties can solve these problems by formalizing and coordinating alternative Nash equilibrium strategies which induce strictly Pareto superior outcomes. Games Two and Three are examples of this when compared to Game One. Game One rationalizes the status quo of 1986 in that it uses welfare weights which induce the action pair, (0, 0), as a Nash equilibrium.

Not every pair of welfare weights, (W_{bi}, W_{ci}), i = us, ec, leads to (0,0) as a Nash equilibrium. It is necessary and sufficient that the welfare weight pair for the US be an element of the set,

(2) $W_{us} = \{(W_{bus}, W_{cus}) \in R_+^2, W_{bus} \leq .781, \text{ and } W_{cus} \leq 1.693 - 1.345W_{bus}\}$,

and that the welfare weight pair (W_{bec}, W_{cec}) be an element of the set,

(3) $W_{ec} = \{(W_{bec}, W_{cec}) \in R_+^2 \text{ and } (W_{cec} \leq .86 - .963W_{bec}\}$.

To show necessity, suppose (W_{bus}, W_{cus}) and (W_{bec}, W_{cec}) induce (0,0) as a Nash equilibrium. Then by definition the US plays option 0 as a best response to the EC playing 0. By definition of best response,

$$V_{us}(0,0) \geq V_{us}(k, 0);\ k = 1, 2, 3.$$

Using (1) and substituting for the values of B_{us}, C_{us}, and P_{us} found in Mahe and Tavera (p. 20), for k = 1, 2, 3,

$$0 \geq 4.74W_{bus} + 0W_{cus} - 3.70,$$

$$0 \geq 6.44W_{bus} + 3.90W_{cus} - 7.62, \text{ and}$$

$$0 \geq 6.79W_{bus} + 5.05W_{cus} - 8.55.$$

Simplifying one obtains

$W_{bus} \leq .781$,

$W_{cus} \leq 1.954 - 1.651W_{bus}$, and

$W_{cus} \leq 1.693 - 1.345W_{bus}$.

These inequalities must hold simultaneously if 0 is a best response. The area identified by the third inequality lies inside that of the second when W_{bus} is less than .781; its line has steeper slope and intersects $W_{bus} = .781$ at a greater W_{cus} than the line boundary of the third inequality. Furthermore (W_{bus}, W_{cus}) is nonnegative by assumption of V_i. Consequently these three equations and nonnegativity reduce to (2); necessity is shown for W_{us}.

Similarly, the EC's best response to the US playing option 0 must also be option 0. By definition of a best response,

$V_{ec}(0, 0) \geq V_{ec}(k, 0)$, $k = 1, 2, 3$.

Using (1) and the values of B_{ec}, C_{ec}, and P_{ec} in Mahe and Tavera (p. 20), rewrite the inequalities as

$0 \geq 2.89W_{bec} + 3.00W_{cec} - 2.58$,

$0 \geq 10.01W_{bec} + 10.84W_{cec} - 16.11$, and

$0 \geq 10.24W_{bec} + 13.08W_{cec} - 18.18$.

Simplifying,

$W_{cec} \leq .86 - .963W_{bec}$,

$W_{cec} \leq 1.486 - .923W_{bec}$, and

$W_{cec} \leq 1.39 - .783W_{bec}$.

The set of points identified by the first equation lies completely within the sets identified by the second two when W_{bec} and W_{cec} are nonnegative. Thus the three inequalities and nonnegativity reduce to (3); necessity is shown for W_{ec}.

To show sufficiency, suppose not. Then there are pairs, (W_{bus}, W_{cus}) and (W_{bec}, W_{cec}) which induces (0, 0) as a Nash equilibrium, but (W_{bus}, W_{cus})

is not in W_{us} or (W_{bec}, W_{cec}) is not in W_{ec}. This implies that nonnegativity or an inequality of W_{us} or W_{ec} is violated. Nonnegativity must hold by assumption of V_i. Therefore an inequality of W_{us} or W_{ec} must be violated. But if it is violated then so is a best response condition for the US or the EC, since the inequality and nonnegativity are equivalent to a best response condition by construction above, so option 0 is not a best response. This contradicts that (0, 0) is induced as a Nash equilibrium. Sufficiency is shown.

Game One uses welfare weights which induce (0, 0) as a Nash Equilibrium. It is summarized by the following payoff matrix.

Table One: Game One Payoff Matrix, (V_{us}, V_{ec})

Player US Option	EC 0		1		2		3	
0	0.00,	0.00	0.08,	-0.05	-0.23,	-7.14	-0.24,	-8.15
1	0.00,	0.07	0.01,	0.06	-0.25,	-7.05	-0.24	-8.06
2	-2.59,	0.27	-2.84,	0.46	-2.55,	-6.93	-2.54,	-7.94
3	-3.25,	0.28	-3.50,	0.48	-3.18,	-6.91	-3.24,	-7.92

$$W_{bec} = W_{cec} = 0.43;\ W_{bus} = .781,\ W_{cus} = 0$$

Game One has two Nash equilibria, (0, 0) which we observe and (0, 1). (0, 0) is a Nash equilibrium by construction of the game. The Nash equilibrium concept only requires that either (1, 0) or (0, 0) be played; it does not predict which will be played.

Game Two

An interesting feature of Game One is that an action pair exists (1, 1) which if played would improve the payoffs for the US and the EC. Nevertheless in this game (1, 1) cannot be sustained, since the EC's best response to option 1 of the US is to play option 0 and the US' best response to option 1 of the EC is to play option 0. But consider an extension of this game. The US and the EC repeat the game every year choosing an action from the same action space and receiving payoffs exactly as before. Game Two is an infinite repetition of Game One. (See MacMillan for an introduction to infinitely repeated games.)

To define the action space for the US and the EC in an infinitely repeated game, at any time t the US and the EC choose actions from A_{us} and A_{ec} defined in Game One. Relabel these spaces A_{ust} and A_{ect}, $t = 1, 2, 3, \ldots$, so $A_t = A_{ust} \times A_{ect}$. By extension the action space of the infinitely repeated game is the infinite Cartesian product, $A = A_1 \times A_2 \cdots$. An element of A is $a = (a_{us}, a_{ec})$, $a_i = (a_{i1}, a_{i2}, a_{i3}, \ldots)$, an infinite sequence containing any combinations of 0's, 1's, 2's, or 3's. a_i is called an action profile. The payoff for i from a_i given a_{-i} is

$$V_i(a_i, a_{-i}) = \textstyle\sum_{t=1}^{\infty} d_i^t \, V_{it}(a_{it}, a_{-it}); \; i = us, ec;$$

where t denotes the time period, where V_{it} is the social welfare function of Game One, where a_{it} (resp. a_{-it}) is the action taken by the i^{th} player (resp. $-i^{th}$ player) at time t, where d_i, $0 \leq d_i < 1$, is player i's discount rate, and where a_i and a_{-i} are action profiles. The definition of a Nash equilibrium for the infinitely repeated game extends from the one-shot game by substituting action profiles for single actions and the present value function for the one period social welfare function.

At time t, a history a^t is a sequence of actions by the US and the EC to time t-1; $a^t = (a_1, a_2, \ldots, a_{t-1})$. For player i, a strategy profile s_i is an infinite sequence of functions which takes any possible history a^t into an action a_{it} for all t; $s_i = (s_{i1}(a^1), s_{i2}(a^2), \ldots)$. Simple strategy profiles can be abbreviated into short sentences, for example, "play option 3 in all periods for all histories." Two strategy profiles will induce two action profiles. Thus the present value for player i of s_i given s_{-i} is the present value arising from the induced action profiles. A Nash equilibrium in strategy profiles requires, however, not only that the induced action profiles be best responses to each other but also that the off-equilibrium paths be best responses. The meaning of the second condition will be clearer when the following treaty is analyzed.

Suppose that the EC possesses a discount rate, d_{ec}, such that $d_{ec} \geq 1/7$ and that the US possesses a discount rate, d_{us}, such that $d_{us} \geq 7/8$. Then a treaty containing the following strategy profiles, s_i, is a Nash equilibrium and induces the action profiles, $a_i = (1, 1, 1, \ldots)$ for i = us, ec, where

$$s_{it} = \begin{cases} \text{play 1 at } t = 1; \\ \text{play 1, if for all } j < t,\ t > 1,\ a_{-ij} = 1; \\ \text{play 0, otherwise.} \end{cases}$$

(The restrictions on d_i reflect necessary conditions for treaty compliance. They do not imply that d_{ec} must differ markedly from d_{us}.)

s_i has two parts; compliance, which is play option 1 as along as the other plays option 1, and retaliation, which is play option 0 forever should -i not comply. Compliance is the equilibrium path, the sequence of actions which the US and the EC will actually play (assuming that compliance is a best response). Retaliation is the off-equilibrium path. The action profiles resulting from retaliation must also be best responses. Intuitively this requires that each country be willing to retaliate according to the treaty should the other not comply with the treaty.

If a government chooses to deviate from the treaty, then it knows that the other government will play option 0 forever after. Option 0 is a best response to this. The action pair (0, 0) is a Nash equilibrium for any single period, so an infinite sequence of (0, 0)'s is a Nash equilibrium for the infinitely repeated game. If it were not then a government at some time t could find an action better than option 0, but this contradicts that (0, 0) is a Nash equilibrium for Game One. Therefore the action profiles induced through retaliation are a Nash equilibrium vector of action profiles.

To show that compliance is a best response, at time $t = 1$, country i calculates two present values: the present value of playing option 1 forever, eternal compliance, knowing that -i will, in turn, also play option 1 forever, and the present value of noncompliance by playing its best response to option 1, which is option 0, and then playing option 0 forever after since -i will retaliate with option 0. Eternal compliance is a best response if and only if its present value is at least as great as the present value of noncompliance.

The present value of eternal compliance for the EC is

$$\sum_{t=1}^{\infty} d_{ec}^{t} V_{ect}(1, 1) = \sum_{t=1}^{\infty} d_{ec}^{t}(0.06) = 0.06d_{ec}/(1-d_{ec}).$$

The present value of noncompliance is

$$d_{ec}V_{ec1}(1, 0) + \sum_{t=2}^{\infty} d_{ec}^{t}V_{ect}(0, 0) = 0.07d_{ec}.$$

Combining these results, eternal compliance is a best response if and only if $0.06d_{ec}/(1-d_{ec}) \geq 0.07\, d_{ec}$. Solving for d_{ec}, $d_{ec} \geq 1/7$. By assumption $d_{ec} \geq 1/7$, so eternal compliance is a best response for the EC.

For the US the present value of eternal compliance is

$$\sum_{t=1}^{\infty} d_{us}^{t} V_{ust}(1, 1) = \sum_{t=1}^{\infty} d_{us}^{t} (0.01) = 0.01d_{us}/(1-d_{us}).$$

The present value of noncompliance is

$$d_{us}V_{us1}(1, 0) + \sum_{t=2}^{\infty}d_{us}^{t}V_{ust}(0, 0) = 0.08d_{us}.$$

Using these results, eternal compliance is a best response if and only if $0.01d_{us}/(1 - d_{us}) \geq 0.08d_{us}$. Solving for d_{us}, $d_{us} \geq 7/8$. By assumption $d_{us} \geq 7/8$, so eternal compliance is a best response for the US. The best responses of the EC and the US are to comply with the treaty in playing option 1 and if retaliation is ever necessary to play option 0. Thus the treaty represents a Nash equilibrium in strategy profiles, and since (1, 1) is played forever, this leads to strictly higher payoffs for the US and the EC.

Game Three

Robert Paarlberg argues that governments lose domestic support and hence endanger their positions in power when they appear too willing to compromise at treaty negotiations. Domestic constituencies want hard bargainers. However an alternative hypothesis is also possible: governments gather domestic support for new policy instruments which would otherwise be politically infeasible because they can bring other governments to accept the same policy instruments through a treaty. As a result a new action space is defined and hence a new game.

The new game is a conjunction of Game One and what is depicted below as Game Three. The conjoined game differs fundamentally from Games One and Two. In Games One and Two, the actions taken by a government do not affect the action space of the other government. Each government always chooses from four possible actions. In the new game both governments must sign the treaty--both must agree to play Game Three--in order to use the new policy instrument. Because the action space of one is constrained by the choice of the other, the new game is a generalized game. Similarly the corresponding solution concept is a generalized Nash equilibrium. This does not affect the noncooperative nature of the game. No government is compelled to comply with the treaty. It will be apparent, however, that both will choose to comply. Consider Game Three.

Game Three extends the action space of Game One. The treaty enables the governments to introduce transfer payments to producers. The payments cannot exceed the amount of budget savings resulting from the introduction of the various options. By inspection of the sets ((2) and (3)) of Nash inducing welfare weights on page three, W_{bus} and W_{bec} are always less than one.

Therefore whichever W_{bi} the governments might possess, they will always choose to transfer any budgetary savings to their producers. Using this fact, the payoff matrix of Game Three is given in table two.

Table Two: Payoff Matrix for Game Three

Player EC

US

Option	0′	1′	2′	3′
0′	0.00, 0.00	0.46, 1.60	0.06, -1.48	0.05, -2.32
1′	1.04, 0.05	1.43, 1.66	1.06, -1.37	1.09, -2.24
2′	-1.18, 0.46	-1.07, 2.34	-0.92, -1.31	-0.92, -2.18
3′	-1.76. 0.48	-1.66, 2.37	-1.48, -1.28	-1.55, -2.17

$$W_{bec} = W_{cec} = .43;\ W_{bus} = .781,\ W_{cus} = 0$$

The ′ denotes the addition of the transfer to the respective option. (1′, 1′) is the unique Nash equilibrium of Game Three. It induces payoffs (1.43, 1.66). For both governments option 1′ is a best response to any action of the other. Reconsidering the conjoined game of Game One and Game Three, the Nash equilibria of Game One and the Nash equilibrium of Game Three are the Generalized Nash equilibria of the new game. Through compliance with the treaty, however, both governments can improve their payoffs.

Concluding Remarks

This paper considers three games based on data from 1986 for US and EC agricultural policy in order to discuss the possible benefits of treaties governing agricultural trade. Game One presents a game which is consistent with the hypothesis that observed policies (the status quo) are Nash equilibria of noncooperative games. Game Two identifies a treaty which formalizes Nash equilibrium strategy profiles of a repeated game. The strategy profiles induce a Pareto improving outcome over the status quo. Game Three portrays the consequences of a treaty which allows the US and the EC to introduce new policy instruments. The resulting Nash equilibrium is a Pareto improvement of the status quo.

The characterization of treaties and current agricultural policies as Nash equilibria imputes rationality to the choices of governments; they do their best given their options and the decisions of others. This behavior does not always lead to the best solutions, witness Game One. However in treaty negotiations, governments create a new game discovering treaties which improve upon the current situation. Although Game Three is the better treaty yielding higher payoffs for both governments for every period in this paper, other games may lead to treaties with which all would comply but among which no treaty is Pareto superior. The problem of multiple Nash equilibria reasserts itself at a higher level. In this case a treaty may only be selected within the political game which each government plays at home. R. Paarlberg's hard bargainer may exist here.

Of course the resolution of the GATT negotiations on agricultural trade will reflect not only the interests of the US and the EC but also the interests of other participants. Furthermore the simple games presented in this paper are only illustrations of what may motivate treaty negotiations. A more realistic model of US and EC behaviors will require more sophisticated action spaces and a more explicit representation of the economic structure which drives the model. Through the explicit use of the economic structure of world agriculture one can consider how structural changes in agriculture will affect the payoffs to governments from alternative policy choices and hence undermine or support treaty compliance in dynamic and not repeated games.

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