How Opportunity Costs Decrease the Probability of War in an Incomplete Information Game

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Abstract This article shows that the opportunity costs resulting from economic interdependence decrease the probability of war in an incomplete information game. This result is strongly consistent with existing empirical analyses of the inverse trade-conflict relationship but is the opposite of the conclusion reached by Gartzke, Li, and Boehmer, who reject the opportunity cost argument in a game-theoretic framework. As a result of our findings, one cannot dismiss the opportunity cost argument as the explanation why trading nations fight less. Instead our study reaffirms the central position of opportunity costs as the basis for the inverse trade-conflict relationship, thus implying that one need not rely on signaling.

Data strongly indicate an inverse relationship between conflict and trade: country pairs that trade the most engage in the least bilateral conflict. One (indeed the predominant) reason for this inverse trade-conflict relationship is opportunity costs that arise because nations tend to forgo trade with combatants, especially when a war erupts. As such, dyadic conflict diminishes bilateral trade that results in lost gains from trade for both nations. To prevent these potential gains from trade losses, trading nations become more cooperative, thereby decreasing the hostility between them. This explanation is know as the "opportunity cost" argument.

A recent influential article in this journal by Gartzke, Li, and Boehmer claims that the opportunity cost argument is incorrect, stating "opportunity costs . . . cannot *deter* disputes."[1] Instead they argue scholars observe an inverse trade-conflict relationship because of "costly signaling." In Gartzke, Li, and Boehmer's model a trading nation signals resolve "without resorting to military violence" by threatening to cut off trade, and as a result this signal leads to less high-level conflict and more overall cooperation.[2] Gartzke, Li, and Boehmer reach this conclusion in

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1. Gartzke, Li, and Boehmer 2001, 392.
2. Ibid., 392.

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two steps. First, within the context of an incomplete information game, they (erroneously) claim that gains from trade do not lead to a reduced probability of war. Second, they show that gains from trade do reduce the probability of war in a game-theoretic "signaling" model. From this they conclude that signaling is the "true" underlying mechanism through which gains from trade operate in reducing bilateral conflict.

We argue in this article that Gartzke, Li, and Boehmer are incorrect to dismiss the opportunity cost model. First, they are mistaken in claiming that trade gains fail to reduce conflict in an incomplete information game—they simply err in their mathematical proof. Second, we argue that without potential gains from trade losses, their signaling model would not yield an inverse trade-conflict relationship. This means even their signaling model relies on potential trade losses associated with conflict. From this we conclude that the opportunity costs of potentially lost gains from trade represent a significant reason why scholars predominantly observe dyads to be more cooperative the more they trade with each other. Our result is consistent with Polachek who derives the inverse trade-conflict relationship using a microeconomic model,[3] as well as with Martin, Mayer, and Thoenig who derive the inverse trade-conflict relationship based on a more general mechanism design game.[4] Our results are significant because they get at the underlying political reason why trade helps deter conflict.

Literature Review

To date a large body of empirical research studies whether trade has a pacifying effect on international conflict, or not. By employing various data samples, a number of regression specifications, and several measures of interdependence, the preponderance of this research finds a pacifying effect.[5] In addition, in recent years, as the growth of foreign direct investment (FDI) exceeded that of international trade, a number of studies began to examine the effect of FDI on international conflict.[6] These studies show empirically that, as with trade, FDI also has a pacifying effect on conflict, implying that FDI has become an important economic force mitigating international conflict. This second strand of literature, therefore, has increased the scope of economic interdependence, making it even more important to understand the underlying reasons for the inverse relationship between interdependence (for example, trade and FDI) and conflict.

3. Polachek 1980.
4. Martin, Mayer, and Thoenig 2008.
5. Barbieri, however, shows that trade increases the probability of conflict (Barbieri 1996). Many follow-up studies have argued her results are not robust: trade shows a pacifying effect on international conflict once more appropriate model specifications are introduced. See Oneal and Russett 1999; and Xiang, Xu, and Keteku 2007.
6. See Gasiorowski 1986; Gartzke, Li, and Boehmer 2001; and Polachek, Seiglie, and Xiang 2007.

Despite the abundance of this empirical literature, little attention has been paid to the underlying formal models behind why economic interdependence lessens dyadic conflict. However, formulating how economic interdependence affects international conflict is a critical step toward better understanding this important phenomenon. Early models were complete information games that led to an opportunity cost argument. This means that nations protect gains from trade by avoiding belligerence and maintaining peace. Other studies question this approach. For example, Morrow states that the relationship between trade and war is ambiguous.[7] He argues that trade affects conflict not because of opportunity costs, but because trade signals resolve. Building on this concept, Gartzke, Li, and Boehmer likewise employ a signaling game in which economic interdependence serves as a costly signal to demonstrate a state's resolve in a world of incomplete information.[8] In their paper, they attempt to demonstrate that the widely cited opportunity cost argument, namely that the benefits of interdependence deter conflict, fails to work in an incomplete information game theoretical framework. They argue the equilibrium probability of war is independent of the opportunity costs associated with interdependence. They claim that since state *A* is aware of the benefit arising from interdependence with state *B*, it will adjust its offer to *B* to subsume this benefit.[9] And as a result of that, they argue, the equilibrium probability for *B* to reject the offer (that is, the equilibrium probability of war) should remain the same.

Their proposition on the effect of opportunity costs is incomplete, however. Since a game involves strategic interactions of both sides, they neglect the effect on the proposing state (that is, state *A*). The benefit from interdependence to the proposer increases its payoff in the case of peace, which also has an impact on the size of the optimal offer. Therefore, it is not true that "opportunity costs generally do not alter the prospects of engaging in costly contests."[10] Indeed, we find opportunity costs arising from economic interdependence can either deter war or reduce the equilibrium probability of war in an incomplete information model like the one examined by Gartzke, Li, and Boehmer.

The Model

The Basic Setup

We use a simple crisis bargaining game to show how opportunity costs associated with economic interdependence generate a lower equilibrium probability of

7. Morrow 1999.
8. Gartzke, Li, and Boehmer 2001.
9. The intermediate step of their reasoning is as follows: state *B* will accept *A*'s offer as long as the associated payoff is no less than the expected payoff of fight. *B* receives additional benefits in the case of economic interdependence but its expected payoff of fight remains the same. As a result, *A* can subtract the benefit of interdependence from its offer and make *B* still accept the offer.
10. Gartzke, Li, and Boehmer 2001, 400.

war. We illustrate this effect of economic interdependence by comparing the equilibrium probabilities of war in two variants of the incomplete information model—one without economic interdependence and the other with economic interdependence.

The presented crisis bargaining game is called ultimatum game. The following is how it looks. Two players—state A and state B—divide a pie valued at W (for example, a piece of territory). State A takes the first move and makes a take-it-or-leave-it offer s_B. Then state B decides whether or not to accept it. The rejection of the offer leads to war and the acceptance leads to a peaceful settlement. Assume the winning state obtains W and the losing side gets nothing, and that war costs are c_A for state A and c_B for state B. Further, assume A wins with probability p. Therefore, in the case of war, the expected payoffs are $pW - c_A$ and $(1-p)W - c_B$ for A and B respectively. In the case of a peaceful settlement, the resulting payoff is $W - s_B$ for state A and s_B for state B.

In the complete information case when everything is public knowledge, in equilibrium state A will offer $s_B^* = (1-p)W - c_B$ and state B will accept it, assuming B will always accept the offer when it is indifferent. In this peaceful settlement, A gets $pW + c_B$ and B gets $(1-p)W - c_B$. To get more interesting cases in which war occurs with positive probabilities, we introduce uncertainty. The critical assumption is that each state knows its war costs, but must presume the other side's costs are drawn from a probability distribution. Following Gartzke, Li, and Boehmer, c_A and c_B are both drawn from a uniform distribution on the $[0,1]$ interval.[11] With this incomplete information on war costs, we show that the equilibrium probability of war is smaller when there is economic interdependence.

Case I: Without Economic Interdependence

First, we examine the case with no economic interdependence. To solve this game, we use the concept of perfect Bayesian equilibrium (PBE)—it requires specifying equilibrium strategies and beliefs for both states. This game can be solved by backward induction. In the first step, we find the equilibrium strategy for state B. That is, B will accept the offer as long as its share of the pie is no less than its expected payoff of war. Mathematically, B's best response is

$$\text{Accept} \Leftrightarrow c_B \geq (1-p)W - s_B$$

$$\text{Reject} \Leftrightarrow c_B < (1-p)W - s_B.$$

Note all the parameters in the above inequalities are known to state B so no uncertainty is involved at this stage of decision making.

11. Ibid., 399.

In the second step, given B's best response at the last move, we find A's best response. Since state A does not observe B's type (that is, c_B), A's optimal strategy is to make an offer of s_B that maximizes its expected payoff given B's best response and A's belief of B's type. In mathematical terms, this means A chooses s_B to maximize the following expected utility

$$\begin{aligned}\text{Eu}_A(s_B \geq 0) = (W - s_B)\Pr(c_B \geq (1-p)W - s_B) \\ + (pW - c_A)\Pr(c_B < (1-p)W - s_B).\end{aligned}$$

Solving the above maximization problem, we find s_B^*—the optimal s_B—as follows:

$$s_B^* = \frac{-1 + 2(1-p)W + c_A}{2}.$$

The first important result is summarized in proposition (1).

Proposition 1. *There is a unique PBE to this game. In the equilibrium, the strategy of state A is to make an offer* $s_B^* = (-1 + 2(1-p)W + c_A)/2$ *and its belief about B's type is* $\mu_{c_B} = 1$. *The strategy of state B is to accept* s_B^* *if* $c_B \geq (1-p)W - s_B^*$ *and to reject it if* $c_B < (1-p)W - s_B^*$.[12]

The equilibrium probability of war is given by the equilibrium probability that state B rejects s_B^*. Mathematically, it is

$$\begin{aligned}\Pr(\text{war}) &= \Pr(B \text{ rejects } s_B^*) \\ &= \Pr(c_B < (1-p)W - s_B^*) \\ &= \frac{1 - c_A}{2}.\end{aligned}$$

Proposition 2. *The equilibrium probability of war for the case with no economic interdependence is* $(1 - c_A)/2$.

As is evident, this probability is solely determined by c_A—state A's type—and it is positive.[13] Next, we want to show this equilibrium probability of war is reduced when adding economic interdependence into the model.

12. Here we do not consider possible mixed strategies which exist in the case $c_B = (1-p)W - s_B^*$.
13. This is because we have a zero probability to have $c_A = 1$, given c_A is drawn from a continuous distribution.

Case II: With Economic Interdependence

With economic interdependence, each state A and B receives a positive supplementary welfare in addition to its share of the pie were there to be a peaceful settlement. In the case of war, economic interdependence will be eradicated so that there is no supplementary welfare, thereby capturing the opportunity costs of lost trade when war results. This is the key assumption employed in the model to test the opportunity cost argument. Let $b_A > 0$ and $b_B > 0$ denote the benefit from interdependence for states A and B, respectively.[14] Assume values of b_A and b_B are known to both states. The resulting change is reflected in the payoffs for the peaceful settlement outcome—in this case state A receives $W - s_B + b_A$ and state B receives $s_B + b_B$ instead. Once again, we solve this game variant via backward induction. First, the best response for B is

$$\text{Accept} \Leftrightarrow c_B \geq (1-p)W - s_B - b_B$$

$$\text{Reject} \Leftrightarrow c_B < (1-p)W - s_B - b_B.$$

Next, given B's best response and A's belief about B's type, A offers s_B, which maximizes the following equation

$$\begin{aligned}\text{Eu}_A(s_B \geq 0) = (W - s_B + b_A)\Pr(c_B \geq (1-p)W - s_B - b_B) + (pW - c_A) \\ \times \Pr(c_B < (1-p)W - s_B - b_B).\end{aligned}$$

When solving this maximization problem we get the optimal s_B to be[15]

$$s_B^* = \frac{-1 + 2(1-p)W + c_A + b_A - b_B}{2}.$$

The equilibrium result for the case with economic interdependence is summarized in proposition (3).

Proposition 3. *There is a unique PBE to this game, and the equilibrium is comprised of two parts. If $1 - c_A - b_A - b_B \geq 0$, A's strategy is to make an offer $s_B^* = (-1 + 2(1-p)W + c_A + b_A - b_B)/2$ and its belief about B's type is $\mu_{c_B} = 1$; B's strategy is to accept s_B^* if $c_B \geq (1-p)W - s_B^* - b_B$ and to reject it if $c_B < (1-p)W - s_B^* - b_B$. If $1 - c_A - b_A - b_B < 0$ (a corner solution exists in this case),*

14. We do not assume b_A and b_B to be necessarily equal to incorporate the notion that states can bargain along the contract curve.

15. We need certain restrictions on the parameter values to obtain the following equilibrium strategy.

A's strategy is to make an offer $s_B^* = (1-p)W - b_B$ *and its belief about B's type is* $\mu_{c_B} = 1$*; B always accepts* s_B^* *in equilibrium.*

The critical observation from proposition (3) is that, with economic interdependence, state A adjusts its offer by the amount of $(b_A - b_B)/2$. This result suggests that A will increase its offer to B should b_A dominate b_B, which is the opposite of what is predicted by Gartzke, Li, and Boehmer. Even in the extreme case where b_A is close to zero—this corresponds to a situation in which only state B benefits from economic interdependence—state A only cuts its offer by half of b_B. Thus, even when incorporating economic interdependence, in no event will state A cut its offer to B by the amount of b_B as suggested by Gartzke, Li, and Boehmer. We will discuss an intuitive explanation of this finding after the presentation of the next equilibrium result.

The probability of war in equilibrium—our quantity of interest—is calculated as before,[16]

$$\begin{aligned}\Pr(\text{war}) &= \Pr(B \text{ rejects } s_B^*)\\ &= \Pr(c_B < (1-p)W - s_B^* - b_B)\\ &= \frac{1 - c_A - b_A - b_B}{2}.\end{aligned}$$

Proposition 4. *If* $1 - c_A - b_A - b_B \geq 0$*, the equilibrium probability of war is* $(1 - c_A - b_A - b_B)/2$*. If* $1 - c_A - b_A - b_B < 0$*, the equilibrium probability of war is* 0.

Proposition (4) shows the most important result of this study: the equilibrium probability of war is lower with economic interdependence—it is reduced from $(1 - c_A)/2$ to $(1 - c_A - b_A - b_B)/2$.[17] In the extreme case—given $(1 - c_A - b_A - b_B < 0)$ is satisfied—a peaceful settlement will be assured. This mathematical result clearly bears out the opportunity cost argument: compared to their counterparts interdependent states are less likely to fight due to the fear of losing economic benefits. This is in contrast to Gartzke, Li, and Boehmer's claim that the probability of war remains the same with economic interdependence.

In addition, proposition (4) suggests that the probability of war is negatively correlated with the economic benefit for each interdependent state—b_A and b_B. This theoretical result is very consistent with the empirical findings that dyadic trade, which is used to approximate benefits of trade for each state, is negatively

16. This probability becomes zero when certain restrictions apply.
17. Recall that b_A and b_B are both positive.

related to the probability of war. Therefore, proposition (4) provides a theoretical foundation for existing empirical research on trade and conflict, and at the same time it is buttressed by existing empirical evidence.

Because examining the same crisis bargaining game[18] has led Gartzke, Li, and Boehmer to reach a completely different conclusion regarding the effect of opportunity costs on the equilibrium probability of war, it is useful to point out their error. Simply put, they make the mistake in the incomplete information case when calculating the optimal size offer state A makes to state B. They base state A's optimal offer on making state B indifferent between accepting the offer and fighting,[19] and in the process they incorrectly assume B's probability of fighting to be independent of A's offer. As such, they treat the probability of war as exogenous when it is endogenous (that is, it varies with the size of offer), and therefore a function of the size of the offer in state A's optimization problem.[20] Put differently, Gartzke, Li, and Boehmer erroneously fix the equilibrium probability of war in their calculations and subsequently obtain the result that the probability of war is 0.5 in equilibrium.[21] This error amounts to turning the incomplete information game into a complete information game.

Discussion

Gartzke, Li, and Boehmer present two incomplete information models: the first without signaling and the second with costly signaling. In the first, they claim opportunity costs play no role in reducing conflict. We show this not to be the case. Opportunity costs do reduce conflict in the incomplete information case with no signaling. The formal models in the last section show that benefits from economic interdependence (that is, b_A and b_B) explain the reduced probability of war in equilibrium. In other words, our finding means economic interdependence—more precisely, the benefit from economic interdependence—deters international conflict, which buttresses the traditional opportunity cost argument of trade. This result is important for two reasons. First, it shows the opportunity cost argument is valid in a game-theoretical framework. Therefore, the opportunity cost argument *can* explain why economic interdependence decreases the probability of war. Second, it provides a theoretical foundation for the empirical finding that trade has a pacifying effect on conflict, and as such implies no necessity to resort to the costly signaling argument to explain why trade deters conflict.

18. See Gartzke, Li, and Boehmer 2001, 398–9, for their description of the game.

19. See the calculations of the expectation of $\partial U_B/\partial f$ in ibid., 421, 423.

20. In our setup of state A's optimization problem, $\Pr(\text{war}) = \Pr(c_B < (1-p)W - s_B)$ in the no gains from trade case, and $\Pr(\text{war}) = \Pr(c_B < (1-p)W - s_B - b_B)$ in the case when there are gains from trade. We can easily see here the probability of war is modeled as a function of the size of the offer (that is, s_B).

21. See Gartzke, Li, and Boehmer 2001, 420, 422 for their setup of state A's optimization problem.

In Gartzke, Li, and Boehmer's second model, resolved states signal their willingness to fight by threatening to cut off trade, thereby forgoing gains from trade. Unresolved states that are unwilling to fight do not forgo the benefits of trade, and as such retain their economic interdependence. The key assumption in this case is that the loss of interdependence is costly (that is, is an opportunity cost) and that the actions to retain interdependence are negatively correlated with state resolve. In short, both opportunity costs and signaling are prevalent. Gartzke, Li, and Boehmer imply as much when they write "states can use opportunity costs as costly signals demonstrating resolve."[22] At any rate, Gartzke, Li, and Boehmer are incorrect to claim "opportunity costs will typically fail to preclude militarized disputes" between interdependent states.[23] Indeed opportunity costs play a major role in incomplete information models without signaling, and in their signaling model, as well.

Appendix

Proof of Proposition 1. First, state B will accept an offer s_B if

$$s_B \geq (1-p)W - c_B$$

$$c_B \geq (1-p)W - s_B$$

and will reject it if

$$c_B < (1-p)W - s_B.$$

Second, the expected payoff for state A with an offer s_B given B's best response and A's belief about B's type is

$$\begin{aligned}\mathrm{Eu}_A(s_B \geq 0) &= (W - s_B)\Pr(c_B \geq (1-p)W - s_B) + (pW - c_A)\Pr(c_B < (1-p)W - s_B)\\ &= (W - s_B)(1 - (1-p)W + s_B) + (pW - c_A)((1-p)W - s_B).\end{aligned}$$

Take the first-order derivative of $\mathrm{Eu}_A(s_B \geq 0)$ w.r.t. s_B and let it equal to 0,

$$\frac{\mathrm{d}}{\mathrm{d}s_B}\mathrm{Eu}_A(s_B \geq 0) = -(1 - (1-p)W + s_B^*) + (W - s_B^*) - (pW - c_A) = 0$$

$$-1 - 2s_B^* + 2(1-p)W + c_A = 0$$

$$s_B^* = \frac{-1 + 2(1-p)W + c_A}{2}.$$

22. Ibid. 404.
23. Ibid. 391.

Take the second-order derivative and get

$$\frac{d^2}{(ds_B)^2} \mathrm{Eu}_A(s_B \geq 0) = -2 < 0,$$

so we have a maximum.[24]

Third, we need to consider two cases in which $(1-p)W - s_B \leq 0$ and $(1-p)W - s_B \geq 1$. In the first case,

$$\mathrm{Eu}_A(s_B \geq 0) = W - s_B,$$

so the best response is to choose $\hat{s}_B = (1-p)W$. In the second case,

$$\mathrm{Eu}_A(s_B \geq 0) = pW - c_A,$$

which is independent of s_B. Let $\tilde{s}_B = (1-p)W - 1$. It is easy to check

$$\mathrm{Eu}_A(\hat{s}_B) \geq \mathrm{Eu}_A(\tilde{s}_B).$$

But, since we have

$$0 \leq (1-p)W - s_B^* = \frac{1-c_A}{2} < 1,$$

it shows s_B^* maximizes $\mathrm{Eu}_A(s_B \geq 0)$ for all $s_B \geq 0$ and s_B^* is the unique equilibrium strategy for state A.

Proof of Proposition 3. First, state B will accept an offer s_B if

$$s_B + b_B \geq (1-p)W - c_B$$

$$c_B \geq (1-p)W - s_B - b_B$$

and will reject it if

$$c_B < (1-p)W - s_B - b_B.$$

Second, the expected payoff for state A with an offer s_B given B's strategy and A's belief about B's type is

$$\begin{aligned}\mathrm{Eu}_A(s_B \geq 0) &= (W - s_B + b_A)\Pr(c_B \geq (1-p)W - s_B - b_B) + (pW - c_A) \\ &\quad \times \Pr(c_B < (1-p)W - s_B - b_B) \\ &= (W - s_B + b_A)(1 - (1-p)W + s_B + b_B) \\ &\quad + (pW - c_A)((1-p)W - s_B - b_B).\end{aligned}$$

24. If $(-1 + 2(1-p)W + c_A) < 0$, we have $s_B^* = 0$.

Take the first-order derivative of $\mathrm{Eu}_A(s_B \geq 0)$ w.r.t. s_B and let it equal to 0,

$$\frac{\mathrm{d}}{\mathrm{d}s_B}\,\mathrm{Eu}_A(s_B \geq 0) = -(1-(1-p)W + s_B^* + b_B) + (W - s_B^* + b_A) - (pW - c_A) = 0$$

$$-1 + 2(1-p)W - 2s_B^* + c_A + b_A - b_B = 0$$

$$s_B^* = \frac{-1 + 2(1-p)W + c_A + b_A - b_B}{2}.$$

Take the second-order derivative and get

$$\frac{\mathrm{d}^2}{(\mathrm{d}s_B)^2}\,\mathrm{Eu}_A(s_B \geq 0) = -2 < 0,$$

so we have a maximum.[25]

Third, we show the equilibrium depends on values of certain parameters. To this end, we need to consider two cases in which $(1-p)W - s_B - b_B \leq 0$ and $(1-p)W - s_B - b_B \geq 1$. In the first case,

$$\mathrm{Eu}_A(s_B \geq 0) = W - s_B + b_A,$$

so the best response is to choose $\hat{s}_B = (1-p)W - b_B$. In the second case,

$$\mathrm{Eu}_A(s_B \geq 0) = pW - c_A,$$

which is independent of s_B. Let $\tilde{s}_B = (1-p)W - b_B - 1$. It is easy to check

$$\mathrm{Eu}_A(\hat{s}_B) \geq \mathrm{Eu}_A(\tilde{s}_B).$$

In order for s_B^* to be an equilibrium strategy, we need

$$0 \leq (1-p)W - s_B^* - b_B \leq 1$$

$$0 \leq \frac{1 - c_A - b_A - b_B}{2} \leq 1.$$

So the condition needed is

$$1 - c_A - b_A - b_B \geq 0,$$

since $(1 - c_A - b_A - b_B)/2 \leq 1$ is satisfied by assumption. On the other hand, if

$$1 - c_A - b_A - b_B < 0,$$

we get equilibrium strategy $s_B^* = \hat{s}_B = (1-p)W - b_B$.

25. Once again, if $(-1 + 2(1-p)W + c_A + b_A - b_B) < 0$, we have $s_B^* = 0$.

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