INAUGURAL ARTICLE

Networks of military alliances, wars, and international trade

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We investigate the role of networks of alliances in preventing (multilateral) interstate wars. We first show that, in the absence of international trade, no network of alliances is peaceful and stable. We then show that international trade induces peaceful and stable networks: Trade increases the density of alliances so that countries are less vulnerable to attack and also reduces countries' incentives to attack an ally. We present historical data on wars and trade showing that the dramatic drop in interstate wars since 1950 is paralleled by a densification and stabilization of trading relationships and alliances. Based on the model we also examine some specific relationships, finding that countries with high levels of trade with their allies are less likely to be involved in wars with any other countries (including allies and nonallies), and that an increase in trade between two countries correlates with a lower chance that they will go to war with each other.

war | networks | international trade | conflict

> Wars are caused by undefended wealth.
>
> Ernest Hemingway (repeated by Douglas MacArthur in lobbying to fortify the Philippines in the 1930s) (1)

> There is only one thing worse than fighting with allies, and that is fighting without them.
>
> Winston Churchill, April 1, 1945 (2)

The enormous costs of war make it imperative to understand the conditions under which wars can be prevented. Although much is known about bilateral conflicts, there is no formal theory of how networks of multilateral international relationships foster and deter interstate wars. We introduce a model of networks of military alliances and international trade that can serve as a foundation for study of international alliance structure and conflict.

The idea of arranging multiple alliances to ensure world peace found perhaps it most famous proponent in Otto von Bismarck and his belief that the European states could be allied in ways that would maintain a peaceful balance of power (e.g., see ref. 3). The alliances that emerged were briefly stable following the unification and expansion of Germany that took place up through the early 1870s but were ultimately unable to prevent World War I. Indeed, many world conflicts involve multiple countries allied together in defensive and offensive groups, from the shifting alliances of the Peloponnesian and Corinthian wars of ancient Greece to the Axis and Allies of World War II, and so studying the fabric of alliances is necessary for understanding international (in)stability.

Between 1823 and 2003, 40% of wars with more than 1,000 casualties involved more than two countries, and many of the most destructive (e.g., the World Wars, Korean War, Vietnam, First and Second Congo Wars, etc.) involved multilateral conflicts.* Most importantly, this is really a network problem. Multilateral wars never involved cliques (fully allied coalitions of more than two countries) against cliques. Out of the 23 wars between 1823 and 2003 that qualify as having at least one side with three or more countries, none of them involved a clique versus a clique. Thus, an approach of modeling networks of alliances, rather than coalitions (in which countries are partitioned into allied groups), is warranted. Also, a network approach meshes well with patterns of international trade, which are critical in determining which countries have incentives to attack or defend which others.

The history of interstate alliances between the early 1800s and the present can be broken into two periods. The early period (pre-1950) involved relatively sparse, very dynamic, and unstable networks, with more than 30% of alliances turning over every 5 years, and many wars. The later period (post-1950) involves networks that are more than four times as dense, and with high stability— with only 5% of alliances turning over every 5 years (see *Data on Trade and Wars*). These differences also correspond to the dramatic drop in wars seen in Fig. 1 as well as a parallel increase in the density of trading partnerships.

To gain insight into the relationship between networks of alliances and the incidence of wars, we model the incentives of countries to attack each other, to form alliances, and to trade with each other. We first define a concept of networks that are stable against wars from a military point of view, when trade is ignored. We show that there are no (nonempty) networks of alliances that are stable, where stability requires that no country be vulnerable to defeat accounting for offensive and defensive alliances, and no country wants to add or drop alliances. This instability is suggestive of the shifting alliances and recurring wars of the 19th and first half of the 20th centuries. Wars, however, have greatly subsided in parallel with the huge increase

Significance

The incidence of interstate wars has dropped dramatically over time: The number of wars per pair of countries per year from 1950 to 2000 was roughly a 10th as high as it was from 1820 to 1949. This significant decrease in the frequency of wars correlates with a substantial increase in the number of military alliances per country and the stability of those alliances. We show that one possible explanation of this is an accompanying expansion of international trade. Increased trade decreases countries' incentives to attack each other and increases their incentives to defend each other, leading to a stable and peaceful network of military and trade alliances that is consistent with observed data.

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*This is based on the Correlates of War (COW) data for which there are data regarding initiators of the war, which we couple with other data for our analysis (See *SI Appendix* for more information) (4). This does not even include the Napoleonic Wars, because the data begin afterward.

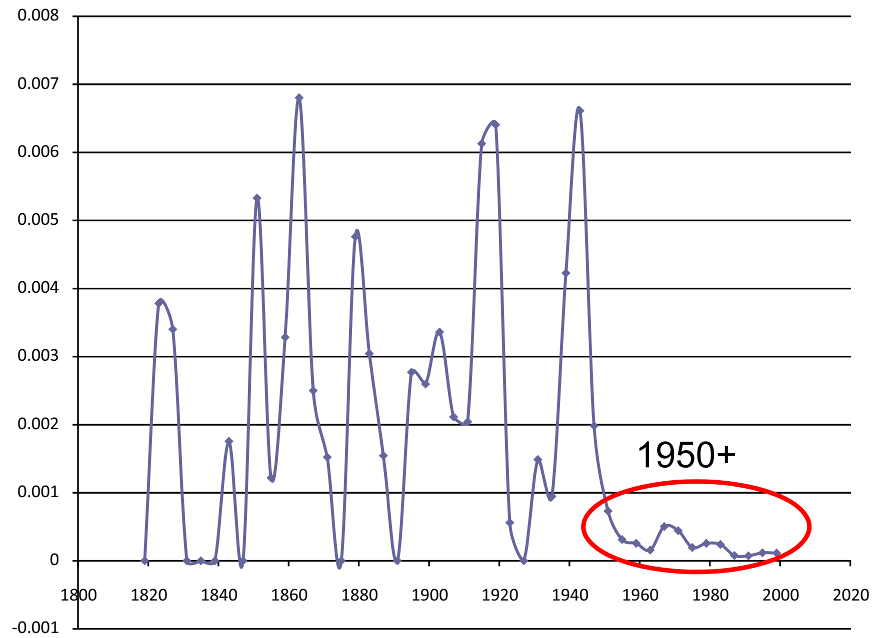

Fig. 1. Wars per pair of countries by year, 1820–2000. (Participant level observations from COW MIDB 4.01 dataset, number of entries with hostility level 5 divided by number of pairs of countries in the COW State System Membership, smoothed via averages over 4-year increments.)

of trade, trends that we discuss in detail below. We thus enrich the base model to include international trade, introducing a concept of a network of alliances being war-and-trade-stable, which allows countries to form alliances for either economic or military considerations. This enables the existence of networks of alliances that are stable against conflict and the addition or deletion of alliances. Trade helps in two ways: First, it provides economic motivations to maintain alliances, and the resulting denser network has a deterrent effect; second, it reduces the incentives of a country to attack trading partners. This reduces the potential set of conflicts and allows for a rich family of stable networks that can exhibit structures similar to modern trade and alliance networks. In examining the data, we find that an increase in the number of a country's allies correlates with a lower frequency with which it is attacked, and increasing trade between two countries correlates with a lower frequency of conflict between them.

We discuss below how the model fits with, and sheds light on, other data and theories, such as the advent of nuclear weapons, the Cold War, and the increase in the number of democracies.

Our analysis fits firmly into the "rationalist" tradition based on cost and benefit analyses, with roots in ref. 5.[†] To our knowledge, there are no previous models of conflict that game-theoretically model networks of alliances between multiple agents/countries based on costs and benefits of wars.[‡] There are previous models of coalitions in conflict settings (e.g., see ref. 12 for a survey). Here, network structures add several things to the picture. Our model examines group conflict (e.g., ref. 13) but enriches it to admit network structures of alliances and of international trade. This allows us to admit patterns that are consistent with the networks of alliances that are actually observed, which are far from being partitions, moving the models toward matching observed patterns of wars, trade, and alliances. Moreover, as we see below both empirically and theoretically, the patterns and number of partners of a given country matter beyond group membership or overall levels of interaction. Finally, our model illuminates the relationships between international trade, stable network structures, and peace, something not appearing in the previous literature—because the previous literature that involves international trade and conflict generally revolves around bilateral reasoning or focuses on instability and armament (e.g., ref. 14) and does not address the questions that we address here. The complex relationship between trade and conflict is also the subject of an active empirical literature (e.g., refs. 15–19). The complex correlations between conflict and trade are illuminated by a model that provides structure with which to interpret some of the observations.

Data on Trade and Wars

Trends in Military Alliance Networks. Marked differences occur between the military alliances we see in the Alliance Treaty Obligation and Provisions Project data at different points in time.[§] There are two major changes that we see comparing the period before to that after 1950 (see also *SI Appendix*). The first major change is that large turnover in alliances, which constantly shift in the period from 1816 to 1950, drops substantially. Specifically, consider an alliance between two countries that is present in year t, and calculate the frequency with which those two countries are still allied in year $t+5$. Doing this for each year from 1816 to 1950, we find the frequency to be 0.695. When doing this for each year from 1950 to 2003 the frequency becomes 0.949. Thus, there is an almost one-third chance that any given alliance disappears in the next 5 years in the pre-WWII period, and then only a 5% chance that any given alliance at any given time will disappear within the next 5 years in the post-WWII period. The second major change is that the

[†]Background can be found in refs. 6 and 7.

[‡]There is a literature that adapts the balance theory of ref. 8 to examine network patterns of enmity (e.g., refs. 9–11). The ideas in those works build upon notions of the form that "the enemy of my enemy is my friend" and are complementary to the analysis underlying the military and trading alliances considered here.

[§]We use alliance data reported by the Alliance Treaty Obligation and Provisions Project (atop.rice.edu) (20), including alliances marked as containing at least one of a defensive, offensive, or consultation provision. The number of countries in the dataset grows over time, and so we adjust on a per-country basis, because otherwise the trends are magnified further. The number of states in 1816 was 23, in 1950 it was 75, and by 2003 it reached 192.

network of alliances greatly densifies. Between 1816 and 1950 a country had on average 2.525 alliances (SD 3.809).[¶] During the period of 1951–2003 this grows by a factor of more than four to 10.523 (SD of 1.918). Thus, there are significantly more alliances per country in the post-1950 than the pre-1950 period.

To summarize, in the pre-WWII period countries have just a couple of alliances on average and those alliances rapidly changed; in contrast, in the post-WWII period countries form on average more than 10 alliances and change much more rarely.

Trends of Wars and Conflicts. Another trend is that the number of wars per country has decreased dramatically post-WWII, even though the number of countries has increased—so there are many more pairs of countries that could go to war. For example, the average number of wars per pair of countries per year from 1820 to 1949 was 0.00059, whereas from 1950 to 2000 it was 0.00006, roughly a 10th of what it was in the previous period. We see this in Fig. 1 (*SI Appendix* shows that this is robust across a variety of methods of measurement). Also, with the exceptions of the anomalous Falklands War, and the Korean and Vietnam Wars—which had Cold War considerations with major protagonists on both sides, including nations outside of Korea and Vietnam—the 24 other Militarized Interstate Disputes (MID) 5s since 1950 involved lesser-developed (lower-trade) countries as the major protagonist on at least one (and often both) sides of the dispute. Moreover, major trading partners at the time do not appear on opposite sides of the dispute.

Trade and Wars. International trade has had two major periods of growth over the last two centuries. The first was from the 1870s through 1913, during which world merchandise exports as a percent of gross domestic product (GDP) grew from 5% to nearly 12%, disrupted by the First World War, and then picking up again after the Second World War, during which exports grew from 7% in 1950 to over 25% by 2012. Putting this trend together with that of wars, we see that the decrease in wars is mirrored by an increase in trade (see *SI Appendix* for more background on trade and war).

Moreover, trade has become less concentrated: In the late 19th century most of the world's trade was concentrated among a small portion of countries, and not all of them traded extensively with each other. Trade is more balanced, and in our model that enables conflict-free networks, and such trade has emerged both in scale and scope mostly in the past six decades. This answers an important puzzle from the data: Export levels in 1913 are similar to those in 1973, and yet the drop in wars occurs from the 1950s onward, and not in the early 20th century. In this regard, our model below is helpful in suggesting a different measure to use than export levels. In our analysis, conflict ends up related not simply to the level of trade, but the patterns of trade partnerships. The numbers of trading partners paint a clearer picture between trade and wars, and a different pattern than the overall level of trade, which turns out to be concentrated among a smaller number of countries before WWI. In particular, as we see in Table 1, the number of trading partners per country is higher in 1950 than in 1913, and the number roughly doubles by 1973, depending on which threshold one uses to define "partner".[#] These numbers do not imply causation because there are many confounding variables that make it difficult to test any theory directly. Nonetheless, this motivates developing a model that predicts which factors matter and how they relate to each other.

Table 1. Average number of trading partners per country

	Year			
Trade partner definition	1870	1913	1950	1973
Partner defined ≥ .1%	3.6	14.2	20.3	34
Partner defined ≥ .2%	3.3	12.7	16.1	26.3
Partner defined ≥ .5%	2.8	10.1	10.3	17.0

A Model of Networks of Alliances

Countries and Networks. $N = \{1, \ldots, n\}$ is a set of countries.

Countries are linked through alliances, represented by a network of alliances, $g \subset N^2$, with the interpretation that if $ij \in g$ countries i and j are allies. So, for instance, the network $g = \{12,23,45\}$ on a set of countries $N = \{1,2,3,4,5\}$ represents situations where country 2 is allied to both 1 and 3, and 4 is allied with 5, and where no other alliances are present. Alliances represent channels through which countries can coordinate military actions, either offensively or defensively. The presence of alliances does not require countries to come to each other's aid, because that will have to be incentive-compatible, as embodied in our definitions below. The operative part of the assumption is that countries either need to have an alliance or add one to coordinate their military activities. $N_i(g) = \{j : ij \in g\}$ are the allies of i.

For a given alliance $ij \notin g$, let $g + ij$ denote the network obtained by adding the alliance ij to g, and for $ij \in g$, let $g - ij$ denote the network obtained by deleting the alliance ij from g. In a slight abuse of notation, let $g - i$ denote the network obtained by deleting all alliances of the form ik, $k \in N$, from g.

Military Strengths and Wars. Each group of countries $C \subset N$ has a collective military strength $M(C)$. Let M_i denote $M(\{i\})$. A prominent example is with $M(C) = \sum_{i \in C} M_i$.[||]

If there is a war between sets of countries C and C', with C being the aggressor, then C "wins" if

$$M(C) > \gamma(C, C')M(C').$$

The parameter $\gamma(C, C') > 0$ is the defensive advantage (of C' over C if $\gamma(C, C') > 1$) or offensive advantage (of C over C' if $\gamma(C, C') < 1$) advantage in the war.

The dependence of the parameter $\gamma(C, C')$ on the groups of countries in question allows the model to incorporate various geographic and technological considerations (e.g., land and sea accessibility between countries, nuclear versus conventional capabilities, troop locations, etc.).[**]

We maintain weak monotonicity conditions on the functions:[††]

- $M(C'') \geq M(C)$ whenever $C \subset C''$: bigger groups of countries in terms of set inclusion are at least as strong as smaller groups.

[¶] If one drops the WWII decade of the 1940s during which most countries were allied in one of two blocs, then this number drops down even further to 1.722 between 1816 and 1940 (standard deviation of 1.366).

[#] GDP numbers per country are generally not available except for a small subset of countries prior to 1950s, which is part of why the merchandise export level data are biased. To try to avoid that bias, we estimate each country's GDP by assigning it a share of world GDP equal to its share of world population (see *SI Appendix* for sources).

[||] Although it would be interesting to endogenize the strengths, for our purposes here we take these as given. For bilateral models of endogenous military strengths see refs. 21 and 22.

[**] The specification is somewhat redundant at this point because one can incorporate everything into the γ function, but this representation will be useful when we specialize it below.

[††] This modeling of a war outcome based on relative strengths is reminiscent of the approach of ref. 23. One could instead work with contest success functions (e.g., as in refs. 22 and 24), which would provide for random chances of winning. In our model it would not add much because we are not focused on arming, and so all that matters is whether the expected benefits exceed a threshold of potential costs/losses.

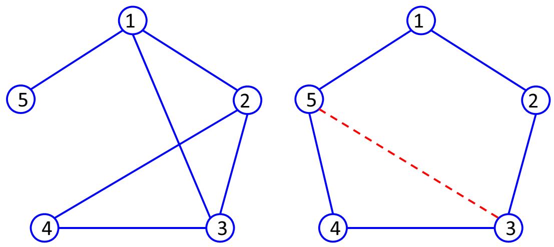

Fig. 2. (*Left*) Country 2, and its allies 3 and 4, attack 1, which is defended by 5. Country 1 is vulnerable if $M(\{2;3;4\})>\gamma(\{2;\ 3;\ 4\},\{1;\ 5\})M(\{1;\ 5\})$. (*Right*) A ring network that is not war-stable for any parameter values.

- $\gamma(C'', C''') \leq \gamma(C, C')$ whenever $C \subset C''$ and $C''' \subset C'$: adding countries to the attacking group and/or subtracting them from the defending group does not increase the defensive advantage.

Vulnerable Countries and Networks. A country i is said to be vulnerable at a network g if there exists j and $C \subset N_j(g) \cup \{j\}$ such that $j \in C$, $i \notin C$ and

$$M(C) > \gamma(C, C')M(C'),$$

where $C' = i \cup (N_i(g) \cap C^c)$ and C^c is the complement of C. In this case, country j is a potential aggressor at a network g.‡‡

Vulnerability is illustrated in Fig. 2, *Left*. Note that country 5 cannot join countries 2, 3, and 4 in attacking country 1 because it is not allied with any of them, and countries 2 and 3 can attack 1 despite being allies with 1.

For a group of countries to attack they must coordinate via some country j, and then the target country i can be defended by its neighbors.§§

Vulnerability just defines the technology of war. If country 1 was vulnerable to attack by 2, 3, and 4, then 5 might have no interest in actually defending 1, which might also give up with minimal resistance. Vulnerability identifies when it is that there is an instability and some country could be attacked successfully.

Incentives and War-Stable Networks. We now introduce the concept of war stability that accounts for countries' incentives to conquer other countries and to add or delete alliances. We first present the definition that does not include trade. The motivation for attacking another country comes from the economic spoils.¶¶ Netted from this are expected damages and other costs of war. The expected net gain from winning a war is then represented as $E_{ik}(g, C)$, which are the total economic gains that accrue to country k if country i is conquered by a coalition C with $k \in C$ when the network is g and i is defended by the coalition $C' = \{i\} \cup (N_i(g) \cap C^c)$.## For example, these include natural resources or other potential spoils of war.

Finally, there are costs to alliances. The cost of country i's having an alliance with country j is some $c_{ij}(g) > 0$. This could include costs of opening diplomatic, military and communication channels, coordinating military operations or intelligence, or other related costs. We generally take costs of alliances to be small relative to the potential spoils of winning a war, because otherwise the analysis is degenerate.*** The costs are also sufficiently small that any country i is willing to pay $c_{ij}(g + ij)$ to add an alliance with j, provided that the addition of the alliance would change i from being vulnerable to not vulnerable.

Define a network g to be war-stable if three conditions are met:

S1 no country is vulnerable at g;

S2 no two countries both benefit by adding an alliance to g; and

S3 no country has an incentive to delete any of its alliances.

Implicit in this definition (in S1) is that if some country were vulnerable, then a group that could defeat the country and its remaining allies would have an incentive to attack and defeat the country—and so that would be unstable. Also, implicit in the definition is that if the country and its allies could be successful in fending off an attack, then they would do so and so things would be stable. For now, we simply assume that winning a war (or successfully aiding an ally in defense) is desired and losing a war is not. When we model trade, we are more explicit about gains and losses.

Given our assumptions on the relative sizes of the spoils of war and the costs of alliances, and that alliances are costly, S2 is equivalent to **S2** $\forall jk \notin g$, no country is vulnerable at $g + jk$, and S3 is equivalent to **S3** $\forall jk \in g$, both j and k are vulnerable at $g - jk$.

This definition is similar to that of pairwise stability (26) in that we consider changes in the network one alliance at a time, and both additions or deletions—requiring two countries to benefit to form an alliance, but only one country to benefit to break an alliance. Given that there is already a large literature on possible variations on definitions of network formation, we focus on this basic definition here.†††

Nonexistence of War-Stable Networks. For the case of two countries, it is direct to check that the only possible stable network is the empty network and it is war-stable only if each country has a sufficient defensive advantage. Thus, we consider the more interesting case with $n \geq 3$.

Before presenting the results on lack of existence of war-stable networks, let us illustrate some of the main insights.

Consider a network like that pictured in Fig. 2, *Right*, the ring network with five countries. In order for 1 not to be vulnerable under the addition of the link 53, it must be that $\gamma(\{2,3,4,5\}, \{1\})M_1 \geq M(\{2,3,4,5\})$ (because it must not be vulnerable to 3 and its allies 2, 4, and 5). However, this implies that 1 is not vulnerable in the original network if it deletes an alliance regardless of the attacking coalition, and so this contradicts war stability.

The following theorem shows that these arguments extend.

Theorem 1. *Let $n \geq 3$. There are no nonempty war-stable networks. The empty network is war-stable if and only if $M(\{j,k\}) \leq \gamma(\{j,k\},\{i\})M_i$ for all distinct i, j, k.*

War-stable networks only exist in the extreme case in which the defensive parameter is so high that the weakest country can withstand an attack by the two strongest countries in the world, in which case the empty network is stable. Outside of that case, there are no war-stable networks. The intuition behind this theorem is similar to that of the example: Outside of the extreme case, requiring that a country not be vulnerable, nor vulnerable

‡‡A country can be both vulnerable and a potential aggressor at some networks.

§§We consider other definitions, presenting analysis with other definitions requiring that attacking and/or defending countries form a clique in *SI Appendix*. We also present data showing that the neighbor case that we consider in the body of the paper is by far the most relevant case (accounting for more than three-quarters of wars from 1823 to 2003).

¶¶Historically, these have included land, natural resources, slaves, and access to markets. For important discussions of the spoils of interstate wars see refs. 14 and 25.

##We allow for the dependence upon the network g, because once we allow for trade, the economic spoils available will be a function of the network.

***In particular, costs are small enough so that if there is some g and $jk \notin g$ such that j is a potential aggressor at $g + jk$, but not at g, with i being vulnerable to being conquered by j, then $c_{jk}(g+jk) + \sum_{s \in N_g(j)} [c_{js}(g+jk) - c_{js}(g)] \leq E_{ij}(g+jk, C)$. Thus, j is always willing to add an alliance to some k that would be pivotal in winning a war.

†††See ref. 27 for an overview of alternative network formation definitions.

to the addition of any alliances, implies that a country has extraneous alliances.

The nonexistence of war-stable networks extends to other definitions of vulnerability, with some interesting variations, as we discuss in the *SI Appendix*.

Nuclear Weapons. An obvious difference post WWII is the presence of nuclear weapons, leading to dramatic changes in the technology of war. Although rarely used, nuclear weapons change the technology.[‡‡‡] However, we emphasize that their existence alone does not lead to stability: Our model (when attacking countries can be joined by their neighbors) allows for completely arbitrary asymmetries in military strengths and in offensive/defensive advantages. There is no way for countries to ally themselves, as a function of their strengths and nuclear capabilities, to produce a stable and nonempty network. The only way in which nuclear weapons could stabilize things would be for all countries to have them and for the empty network to ensue. This is clearly not the case.

Therefore, one needs to add trade, or some other consideration, to the model to explain why we see denser networks that are stable and why many nonnuclear countries also live in relative peace. Thus, we turn to the analysis of the stability when there are substantial trade considerations.

War and Trade-Stable Networks. We now generalize the model to include payoffs that accrue to countries as a function of the network as a result of trade.

Country i gets a payoff or utility from the network g given by $u_i(g)$, representing the economic benefits from the trade as a function of the network g.

A link now represents both a potential trading relationship and potential to coordinate military activities. The assumption is that if two countries trade (significantly) with each other, then they can come to each other's aid in the event of a military conflict—so the military aspect of an alliance does not need to be made explicit if there is trade. The two assumptions that we are using are thus: (*i*) Having an "alliance" involves costs, however tiny, that must be offset by some benefits either via trade or war; and (*ii*) without having any relationship, countries are not able to coordinate either in attacking or in defending. Without (*ii*) "alliances" have no real meaning. Alliances can be fairly inexpensive but still serve a purpose of making clear who could defend whom in various situations.[§§§]

The presumption that substantial trade allows for potential military coordination captures the idea that both the interests and channels of communication needed for military coordination are present, regardless of whether there is then an explicit military alliance. An example is the US aid to Kuwait in the Persian Gulf War.

Vulnerability and Stability with Trade. We now introduce a concept of vulnerability based on the incentives of countries to attack others when accounting for the benefits and costs, including trade consequences, associated with conquering a country.

A country i is vulnerable despite trade in a network g to a country j and coalition $C \subset N_j(g) \cup \{j\}$ if $j \in C$, $i \notin C$ and

- $M(C) > \gamma(C, C')M(C')$, where $C' = \{i\} \cup (N_i(g) \cap C^c)$ (i.e., C could conquer i), and
- $u_k(g-i) + E_{ik}(g, C) \geq u_k(g)\ \forall k \in C$ with some strict inequality: Every $k \in C$ would benefit from conquering i, factoring in economic gains of conquering and gains or losses in subsequent payoffs from the network.[¶¶¶]

The second item is new to this definition of vulnerability and incorporates two aspects of economic incentives of countries to attack each other: $E_{ik}(g, C)$ represents the potential net benefits that k enjoys from conquering i as part of the coalition C in a network g. If a country is poor in natural resources, and much of its economy is built upon nontransferable or difficult-to-extract human capital, it would tend to have a lower E_{ik} and would be less attractive. $u_k(g-i)$ accounts for the fact that as i is conquered then the network of trade will adjust. If k is a trading partner of i, then k could lose via the elimination of i, with $u_k(g-i) < u_k(g)$.[###] Note that this effect can work both ways: It might also be that a country k benefits from the elimination of some country i.

With this framework, we now define a stability notion corresponding to war stability but adding the economic considerations. Our definition of war and trade stability incorporates two incentives for adding or deleting alliances. First, countries might add or maintain an alliance because of its military value in either preventing a war or in instigating one, just as with war stability. This is similar to what we considered before, except that countries now consider the economic spoils and consequences of war in deciding whether to take part in an attack. Second, countries add or maintain alliances for the economic benefits in terms of trade.

Consider the incentives for countries to add an alliance and attack another country. Starting from a network g, some alliance $jk \notin g$ is war-beneficial if there exists some $C \in N_j(g+jk) \cup \{j\}$ with $j \in C$, $k \in C$, and $i \notin C$ such that i is vulnerable despite trade to C at $g+jk$ and

- $u_j(g+jk-i) + E_{ij}(g, C) \geq u_j(g)$, so, j would benefit from forming the link and attacking, and
- $u_k(g+jk-i) + E_{ik}(g, C) \geq u_k(g)$, similarly for k, with one of these inequalities holding strictly.

A network g is war-and-trade-stable if three conditions are met:

ES1 no country is vulnerable despite trade at g;

ES2 $\forall jk \notin g$: if $u_j(g+jk) > u_i(g)$ then $u_k(g+jk) < u_k(g)$, and also jk is not war-beneficial

ES3 $\forall jk \in g$ either $u_j(g-jk) \leq u_j(g)$ or j is vulnerable despite trade at $g-jk$, and similarly for k.

So, a network of alliances is war-and-trade-stable if no country is vulnerable despite trade, if no two countries can add an alliance and both profit either through economic or war means, and either economic or war considerations prevent any country from severing any of its alliances.[****]

We say that a network g is strongly war-and-trade-stable if it is war-and-trade-stable for any (nonnegative) specification of the E_{ij} s.

[‡‡‡]There is a large literature on the Cold War and a contentious debate on the potential stabilizing or destabilizing impact of nuclear technology (e.g., see refs. 28–30).

[§§§]A more complicated model could involve incomplete information about alliances so that making public a nonbinding alliance is useful, as in ref. 31.

[¶¶¶]It is not essential whether the strict inequality is required for all countries or just some, or must include j, because for a generic E function there will not be equality for any countries.

[###]As ref. 18 documents, the economic loss resulting from trade disruption during wars can be of the same order as more traditional estimates of losses resulting from interstate conflict. This does not even account for the potential loss of trade if a partner is lost altogether. Here we do not model later recovery of a country or future networks, but clearly the model extends as long as there are some potential short-term gains and losses from war. Also, we abstract from the political decision making and how gains from trade and spoils might be distributed within a country, an important topic for further research.

[****]Note that if $u_i(\cdot)$ is constant for all i, then war and trade stability reduces to war stability.

Existence of War-and-Trade-Stable Networks. We begin our analysis of war-and-trade-stable networks by identifying a condition that is sufficient for war-and-trade stability.

Proposition 1. *Suppose that g is pairwise stable with respect to u.*[††††] *If no country is vulnerable despite trade at g or $g+jk$ for any $jk \notin g$, then g is war-and-trade-stable. Moreover, if no country is vulnerable at g or $g+jk$ for any $jk \notin g$, then g is strongly war-and-trade-stable.*

The proof of the proposition is straightforward and thus omitted.

There are many examples of networks that are war-and-trade-stable but not war-stable, because any of the nonempty ones below will satisfy that criterion. The following theorem outlines classes of war-and-trade-stable networks, showing that economic considerations restore general existence results.

For the following constructive results, we specialize to the case of symmetric countries (so the $u_i(\cdot)$, $E_{ij}(\cdot)$, and M_i s are independent of i and j) and where $\gamma(\cdot)$ is a constant, but it should be clear that similar results extend to the asymmetric case under more complicated conditions.

We also consider a canonical case in which

$$u_i(g) = f(d_i(g)) - c \cdot d_i(g),$$

where $d_i(g)$ is the degree of i and f is concave, nondecreasing, and such that there exists some $d \le n-1$ such that $f(d) < c \cdot d$. This is a simple model of gains from trade and costs of having trading relationships, abstracting from heterogeneity in goods and trading partners and interdependencies in trading relationships beyond diminishing returns—again it should be clear that similar results hold for richer models. Let d^* maximize $f(d) - c \cdot d$ among nonnegative integers.

In addition, let $E_{ij}(g, C) = E(d_i(g))/|C|$, so that each country's economic spoils from a war depend only on that country's degree, and then are divided equally among the attacking countries.

Theorem 2. Consider the symmetric model with $d^* \ge 2$.

- Any d^*-regular network (i.e., such that each country has d^* alliances) for which no two countries have more than $k < d^* - 1$ allies in common is strongly war-and-trade-stable network if $\gamma \ge (d^*+1)/(d^*-k-1)$.
- If $E(d^*) \le 2[f(d^*) - f(d^*-1) - c]$, then any d^*-regular network (in any configuration, including combinations of cliques) is a war-and-trade-stable network if $\gamma \ge (d^*+1)/(d^*-1)$.

The theorem's two existence results reflect different mechanisms. The first part reflects that if countries have incentives to maintain multiple relationships for trade purposes, then that can result in an alliance network such that no country is vulnerable (even with the addition of new alliances). Stability then requires specific network structures (for example, simply forming cliques where each country has d^* allies will not work, because then all of a country's partners can attack the country and win). This part of the result works off of incentives for countries to defend one another. The second result reflects that, with sufficient gains from trade, the potential spoils of a war against a trading partner are outweighed by the lost trade value—and so countries are never attacked by one of their own allies. This result thus also incorporates a lack of incentives for a country to attack a trade partner, in which case with a sufficient number of alliances a wider range of networks becomes stable. This allows more cliquish structures to be stable.

[††††] Pairwise stability is the requirement that no two countries weakly benefit from adding a link (at least one strictly), and no single country benefits from deleting some link.

Table 2. Logistic regressions of dyadic war on dyadic trade

	(1)	(2)
Dyad trade	−1,974.37***	
	(383.69)	
Lagged dyad trade		−1,150.24***
		(248.29)
Observations	36,832	35,658

SEs in parentheses. Logit regression of dyad in conflict on dyadic trade, including decade dummies and dyads within 1,000 km of each other. Dyad at war if involved on opposite sides of an MID 5. Dyad trade is normalized by the minimum of the two countries' GDPs. Conflict data from COW. Trade and GDP data from ref. 32. Distance data from ref. 33. ***$P < 0.01$.

Another Look at War and Trade Data

The model suggests some dimensions that are important in determining peace. For instance, as just discussed, a country having more allies (who are trading partners) and having more trade with them would lead the country to be less prone to attack. Also, the country should be less prone to being attacked by countries that trade with it substantially. Before closing, we take a brief look at these effects in the data, and we concentrate on the period of 1950–2000 for which we have detailed trade and GDP data (from ref. 32).

Table 2 reports a logistic regression of the probability that two countries are at war with each other in a given year as a function of the level of trade between the two countries, where the level of trade between the two countries is a measure of the total exchanged (imports plus exports) divided by the maximum of the GDPs of the two countries as a normalizer. We limit attention to countries within 1,000 km of each other because most other dyads are much less likely to be at war or trade with each other. We also consider war to be a MID 5 according to the COW dataset.

In Table 2 we see a large and significantly negative relationship between the trade between two countries and the chance that they will go to war.[‡‡‡‡] To get an idea of the magnitude of the effect, a 1 SD (0.0087) increase in the normalized dyadic trade decreases the log odds ratio that two countries are at war with each other by a factor of more than 17 (based on the coefficient from column 1)—basically taking the odds ratio to 0.

In the *SI Appendix*, we show that similar results hold when we only look at new wars (the first year that countries are at war), and we also analyze how the probability that a country is at war with some other country in a given year depends on the number of trading partners that the country has (i.e., the number of countries with which the country trades at least 0.5% of its GDP), as well as the total trade that the country has with its partners normalized by its GDP, showing that these both significantly decrease incidence of wars. For instance, we find that adding 10 allies (just under the mean) decreases the odds that a country is at war by over 50%.

Discussion

We provided a model of networks of military alliances and the interactions of those with international trade. We showed that regardless of military technologies and asymmetries among countries, nonempty stable networks fail to exist unless trade considerations are substantial. Moreover, the network perspective gives us an understanding of how trade might prevent conflict, by discouraging countries from turning against their allies

[‡‡‡‡] The result in ref. 3 is robust to the inclusion of country fixed effects, clustered standard errors, and controls for the decade, although the coefficient on lagged trade (5) loses significance when clustered at the dyad level (see *SI Appendix*).

and encouraging countries to defend their trade partners. Although this points to trade as a necessary condition for stability, whether it is sufficient for stability depends on size of the costs and benefits of war.

In closing, we comment on several other features of international relations that are part of the larger picture of interstate war. A notable change in alliances during the Cold-War period was from a "multipolar" to a "bipolar" structure, something which has been extensively discussed in the Cold-War literature (e.g., see ref. 12 for references). Although this lasted for part of the postwar period, and was characterized by a stalemate between the Eastern and Western blocs, such a system of two competing cliques of alliances is only war-stable if there are sufficient trade benefits between members of a clique, as shown in our second theorem. Moreover, it is more of a historical observation than a theory, and it does not account at all for the continued peace that has ensued over the last several decades. Thus, this fits well within the scope of the model and does not account for the overall trend in peace.

Another institutional observation regarding the post-WWII calm is that institutions have allowed for coordination of countries onto a peaceful "collective security" equilibrium where any country disrupting international peace is punished by all other countries, so that war against one is war against all. However, as shown by ref. 34, this equilibrium is in some sense "weak": It relies heavily upon the assurance that a country tempted to join an attacking coalition will refuse and that all countries will follow through on their punishment commitments, so that far-sighted expectations of off-equilibrium behavior are correct. Given that various small conflicts since WWII did not precipitate a global response, such doubts of some countries' commitment to follow through on punishments seem reasonable.[§§§§] Although collective security does not seem to explain the lasting peace, it nonetheless does suggest an interesting avenue for extension of our model: taking a repeated games approach to networked conflict and trade.

One more relevant observation regarding changes in patterns of conflict is the so-called democratic peace: Democracies rarely go to war with each other.[¶¶¶¶] This coupled with a large growth of democracies might be thought to explain the increase in peace. However, once one brings trade back into the picture, it seems that much of the democratic peace may be due to the fact that well-established democracies tend to be better-developed and trade more. Indeed, studies (38, 39) indicate that poor democracies are actually significantly more likely to fight each other than other countries, and that paired democracy is only significantly correlated with peace when the countries involved have high levels of economic development, which is consistent with trade's playing the major role rather than the government structure. Our model abstracts from political considerations, which still could be significant, and so this suggests another avenue for further extension.[####]

We close by noting some additional directions for further research. One is that both trade and war have strong relationships with geography (see, e.g., ref. 42 as well as ref. 25, in which the authors find that from 1945 to 1987 86% of significant international wars were between neighboring states). Because geography constrains both the opportunities and benefits from trade and war, it has ambiguous effects on stability. Nonetheless, it plays an important role in explaining realized networks of trade and alliances and deserves further attention. A second direction concerns expanding the scope of the paper. Although we have focused on interstate war, there are analogous forces at work in civil wars in which there are multiple parties involved, as well as other settings in which there may be multiple groups or factions with competing interests and possibilities of gainful alliances (e.g., firms in an industry with possible research collaborations or product tie-ins, or political parties with possible vote trading). The broad prediction of increased trade interests enabling more cooperative behavior overall would be interesting to explore more generally.

Proofs

Proof of Theorem 1. The conditions on stability can be recast as requirements on the γ parameter.

Consider a country that has an alliance in a nonempty network, say i, which then has alliance to some k. In order for [S3] to be satisfied, it must be that i is vulnerable in $g-ik$. Thus, there is some j and $C\subset N_j(g-ik)\cup j$ with $i\notin C$ and $M(C)>\gamma(C,C')M(C')$ for every feasible C' out of all $C'\subset\{i\}\cup N_i(g-ik)\cap C^c$ that can defend i. Given [S1], it must be that i was not vulnerable at g, and so it must be that $k\notin C$ and in particular that $jk\notin g$. However, if the link jk is added (so that the network $g+jk$ is formed), then $C\cup\{k\}$ can defeat i, because $M(C\cup\{k\})\geq M(C)$ and also $\gamma(C\cup\{k\},C')M(C')\leq\gamma(C,C')M(C')$ for any feasible $C'\subset\{i\}\cup N_i(g)\cap(C\cup\{k\})^c$ that can defend i, and so

$$M(C\cup\{k\})\geq M(C)>\gamma(C,C')M(C')\geq\gamma(C\cup\{k\},C')M(C')$$

for any feasible $C'\subset\{i\}\cup N_i(g)\cap(C\cup\{k\})^c$ that can defend i. This violates [S2] as then j and k benefit from adding the link because i is vulnerable to a coalition containing both j and k, which is a contradiction. This establishes that any network that is war-stable must be empty. The second sentence of the theorem is obvious.

Proof of Theorem 2. We apply *Proposition 1*. It is clear that any network that is d^* regular is pairwise stable. Thus, we need only show that no country is vulnerable despite trade and that this remains true with the addition of any link. For the first part of the theorem we also need to show that this is true regardless of $E(\cdot)$ for at least some d^*-regular networks. For the second part of the theorem, we need to show this is true under the given assumption on $E(\cdot)$, but for any d^* regular network.

First, note that no country i is vulnerable to any coalition C that does not include any of its neighbors (even if this comes from the addition of a link not involving any neighbors), because under either part of the theorem $\gamma\geq(d^*+1)/(d^*-1)>(d^*+2)/(d^*+1)$. Thus, we need only verify vulnerability to a coalition that involves at least one neighbor, and might possibly involve the addition of a link.

So, consider a country i and a coalition C that involves at least one of its neighbors. Under the first part of the theorem, the maximum strength of the coalition (involving adding a link) would be d^*+2 (if lead attacker is not one of i's neighbors) and then the defending coalition would involve at least d^*-k members, or else the lead attacker is one of i's neighbors, in which case the strength is at most d^*+1 and the defense involves at least d^*-k-1 members. Given that $\gamma\geq(d^*+1)/(d^*-k-1)$, it follows that $\gamma\geq(d^*+2)/(d^*-k)$, and so i is not vulnerable in either case.

Under the second part of the theorem, if some neighbors of i in C still has only d^* links, then because $E(d^*)/2\leq f(d^*)-f(d^*-1)-c$, and the attacking coalition must involve at least two countries (given γ and i at a minimum defending itself),

[§§§§]One might think of the rise of international institutions as allowing larger groups of countries to simultaneously add alliances, rather than the pairwise addition in our base model below. However, this only decreases the set of potentially war-stable networks, once again indicating that trade needs to be incorporated into a model of alliances.

[¶¶¶¶]For early background see refs. 35–37, and more recent references can be found in ref. 7.

[####]For example, ref. 40 discusses how term limits and electoral accountability affect the incentives to go to war, and ref. 41 discusses the divergence of the incentives, between politicians and the population that they represent, to go to war.

then that country would not be willing to follow through with the attack of i. Thus, all of i's neighbors in the coalition C must have formed a new link (and so have degree d^*+1) in order to be willing to follow through with the attack. This implies that the coalition involves at most two of i's neighbors (since at most one link is added), but then because $\gamma \geq (d^*+1)/(d^*-1) \geq (d^*+2)/d^*$, the attacking coalition cannot defeat i and its remaining neighbors, regardless of whether it involves one or two of i's neighbors.

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