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Trading Communities, the Networked Structure of International Relations, and the Kantian Peace

Yonatan Lupu[1] and Vincent A. Traag[2]

Abstract

The authors argue that theories regarding the relationship between trade and conflict could benefit greatly from accounting for the networked structure of international trade. Indirect trade relations reduce the probability of conflict by creating (1) opportunity costs of conflict beyond those reflected by direct trade ties and (2) negative externalities for the potential combatants' trading partners, giving them an incentive to prevent the conflict. Trade flows create groups of states with relatively dense trade ties, which we call trading communities. Within these groups, the interruptions to trade caused by conflict create relatively large costs. As a result, joint members of trading communities are less likely to go to war; however little they directly trade with each other. The authors systematically measure and define trading communities across various levels of aggregation using the network analytic tool of modularity maximization. The authors find significant support for their hypothesis, indicating that interdependence theory can be extended to extra-dyadic relations.

[1]Department of Political Science, George Washington University, USA
[2]Department of Mathematical Engineering, Université Catholique de Louvain, Louvain, Belgium

Corresponding Author:
Yonatan Lupu, Department of Political Science, George Washington University, 2115 G Street, NW, Washington, DC 20052, USA.
Email: ylupu@gwu.edu

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Although scholars have long recognized that interdependence is complex, the literature on the relationship between trade and conflict has often overlooked this complexity. Most studies of this relationship have focused strictly on dyadic relations, thus making the theoretically and statistically problematic assumption that the thousands of dyadic relationships between states do not affect each other (Ward, Siverson, and Cao 2007). In other words, we have assumed independence in order to study interdependence. One of the most important drawbacks of this approach is that it looks only at the ways in which direct trade dependence affects conflict behavior, ignoring the ways in which indirect trade relations may do so and leaving gaps in our understanding of the relationship between trade and conflict. Several recent studies have begun to relax these assumptions, providing evidence that extra-dyadic trade relations have important effects on interstate conflict (Maoz 2006, 2009; Böhmelt 2009; Dorussen and Ward 2010; Ward and Ahlquist 2011). Yet, important questions remain. First, how does indirect trade dependence reduce the probability of interstate conflict? Second, at what level of aggregation are these effects relevant?

We begin by explaining the causal mechanisms by which indirect trade relations reduce the probability of conflict. Traditional analyses focus on states' direct trading relationships, arguing that the conflict-reducing effects increase with the extent to which pairs of states are more directly dependent on each other for trade. Yet, these approaches miss the ways in which interdependence reduces conflict even among states that are not directly dependent on each other. We depart from existing theory by arguing that indirect trade dependence reduces the probability of dyadic conflict, regardless of the level of dyadic trade dependence. This occurs for two reasons. First, indirect trade ties create significant opportunity costs of war. The traditional argument regarding opportunity costs is that they are incurred when war cuts off profitable trade between combatants. Yet, war often also cuts off the combatants' trade with other states, thus creating additional opportunity costs of war for the combatants not reflected in existing theories that focus on direct trade. Second, these cutoff trade flows create negative externalities for the combatants' trading partners, whose import supplies and export markets are jeopardized. These costs create an incentive for these trading partners to prevent the conflict.

Our second key point is that these processes are likely to be significant not only at the dyadic and systemic levels but also especially significant at the subsystemic level of trading communities. In developing our argument, we demonstrate how the trade-and-conflict literature can be enriched by incorporating important insights from two other literatures: network theory and the scholarship on regional subsystems and security communities. We develop the concept of a trading community, or a group of states with relatively large trade flows among them. Our theory predicts that states that are members of the same trading community are less likely to experience conflict with each other, regardless of the extent to which they trade directly with each other. Our research design relies on measuring and defining these communities using the network-analytic tool of modularity maximization. We find robust evidence to support the notion that states that are joint members of a trading community are less likely to experience a militarized dispute, regardless of their level of direct trade dependence.

Direct Trade and Conflict

Theories about the relationship between trade and conflict have a long tradition in international relations scholarship. Most of these focus on bilateral relationships, explaining whether and how increased levels of trade between two states affect their probability of direct conflict. A smaller body of work also examines the ways in which dyadic dependence affects the probability of systemic conflict, although the findings from this work remain tentative (Oneal and Russett 1999, 2005; Gartzke 2010). Recent work has begun using network analytic measures to demonstrate that indirect trade relations also have important effects on interstate conflict (Maoz 2006, 2009; Böhmelt 2009; Dorussen and Ward 2010). We build on this burgeoning literature by explaining the relationship between such ties and conflict and by bridging it with other work that focuses on the roles of communities, subsystems, and other indirect ties in international relations.

The main strand of interdependence theory relies on the argument that close economic relations, particularly trade, reduce conflict by changing state incentives (Angell 1933). This school of thought focuses on a cost–benefit analysis, arguing that trade increases the opportunity costs of war, thus making conflict less likely (Rosecrance and Stein 1973; Polachek 1980). Trade, others argue, also allows states to efficiently gain resources through economic, rather than military, means (Rosecrance 1985). While a significant number of scholars have argued against this position (Buzan 1984; Barbieri 1996), recent evidence suggests that the more states trade with each other directly, the less likely they are to go to war (Oneal, Maoz, and Russett 1996; Gartzke, Li, and Boehmer 2001; Oneal, Russett, and Berbaum 2003). In addition, trade institutions, especially Preferential Trade Agreements, strengthen the conflict-reducing effect of interstate trade (Mansfield, Pevehouse, and Bearce 1999; Mansfield and Pevehouse 2000). Scholars have also theorized that economic ties other than trade, especially open markets, similarly decrease the probability of conflict by making it less attractive compared to other means of improving welfare (Stein 1993; Doyle 1997).

The nature of the causal relationship between trade and conflict is known to be complex. States (and, in turn, firms) select their trading partners in part based on their political relations with the home state, suggesting that the trade–conflict relationship runs in both directions. There is nonetheless strong evidence that, while trade does appear to follow the flag, it also reduces the probability of conflict. Kastner (2007) argues that the extent to which negative political relations affects trade depends in part on the political clout of domestic economic actors. Others use simultaneous equation modeling to demonstrate that, taking into account the negative impact of conflict on trade, trade nonetheless reduces the probability of conflict (Hegre, Oneal, and Russett 2010).[1] The network approach we adopt does not directly address this problem, although it does not exacerbate it. Nonetheless, recent work by economists argues that networked actors may have incentives to trade that are not captured by dyadic analyses (Goyal and Joshi 2006). While states may have some capability to strategically choose their trading partners, they may be less likely to be able to influence their trading partners' choice of trading partners. In addition, firms facing the political risks or barriers associated with certain potential direct trading relationships may choose to bypass those issues by creating indirect trade routes through third-party states. These processes could result in indirect trade ties between politically hostile states, which may be overlooked in a strictly dyadic analysis. While we do not directly examine these mechanisms in this article, the foregoing suggests additional ways that scholars might be able to further disentangle the trade–conflict relationship by using a networks approach.

Trading Communities

A significant limitation of the existing literature is its almost exclusive attention to direct trading relationships. As Maoz (2009) puts it, "[f]ocusing only on direct ties ignores an enormously important feature of interdependence" (p. 224). Analyzing only dyadic trade relations oversimplifies the complexity of interdependence and, as a result, loses sight of the ways in which trade reduces conflict even among states that trade very little with each other. We argue that indirect trade dependence creates significant costs of conflict in addition to those created by the levels of direct trade between states. In addition, the conflict-reducing effects of interstate trade are heightened within groups of states we call "trading communities." We define a trading community as a group of states that trade with each other significantly more than they trade with states outside the community. We develop this argument in two parts. First, we explain how thinking of trade relationships not as independent dyads but as a complex network allows us to see how indirect trade dependence affects conflict. Second, we explain why the mechanisms by which indirect trade dependence reduces conflicts are especially powerful within trading communities. We then develop and test a hypothesis about the relationship between trading communities and conflict.

How Indirect Trade Dependence Reduces Conflict?

Several important studies have provided evidence that indirect trade relations reduce conflict. The probability of conflict is lower among dyads with more trading partners in common (Maoz 2009; Dorussen and Ward 2010) and among dyads that are generally more well connected to other states in the trade network (Dorussen and Ward 2010). Yet, this literature has not fully explained the causal mechanisms underlying these effects. Dorussen and Ward (2010) argue that the key mechanism at work here is informational: trade decreases the likelihood of conflict by facilitating regular interaction, informational exchange, and cultural exchange. While acknowledging this important contribution, we argue that indirect trade relations reduce the probability of conflict in two additional ways, which we refer to as the "Combatant Mechanism" and the "Noncombatant Mechanism."

Our argument builds on several behavioral patterns believed to be at work when relationships are networked. One is that an actor A has incentives to maintain peaceful relations between his contacts (B and C) in part because conflict between the latter could cause stress or otherwise impose costs on A (Rapoport 1953; Heider 1958; Granovetter 1973; Bearman and Moody 2004). The inverse of that logic is also at work: B and C will seek to improve their relationship with each other in order to secure their valued relationship with A. If two actors B and C have positive relationships with A, then they are likely to have positive relations with each other (Heider 1946; Cartwright and Harrary 1956). Examining networked trade relations allows us to look at these higher-order dependencies in the relations between states to determine how indirect trade ties may affect the probability of conflict.

The combatant mechanism. That trade between potential combatants may affect their incentives to fight has long been recognized; yet, we argue that these incentives may also be affected by their trade relationships with other states. We build on the opportunity-cost theory of interdependence. Traditional formulations of this argument focus on the extent to which the potential participants in a conflict stand to have their trade with each other interrupted or otherwise adversely affected (Angell 1933; Polachek 1980; Oneal, Maoz, and Russett 1996; Oneal, Russett, and Berbaum 2003). Conflict, Polachek (1980) argues, adversely affects the terms of trade between states, including by increasing the likelihood of "retaliatory tariffs, quotas, embargoes, and other trade prohibitions" (p. 60). Anderton and Carter (2001) find empirical evidence that wars are associated with declines in trade (although the evidence is weaker when major powers are not involved). Thus far, the opportunity-cost model has focused on the potential effects of conflict between a pair of states on their trade with each other. If a pair of states trades with each other relatively little (or not at all), this theory would predict that trade would have little effect on the probability of a war between them.

Yet in a world of complex, networked trade relationships, conflict may also interrupt trade flows other than those between the potential combatants. Although a pair of states may not have a trade relationship with each other, they would jeopardize their trading relationships with other states by going to war, and therefore have a disincentive to do so. Entering a conflict could interrupt a state's trade with states not involved in the conflict in various ways. Trade relations are highly interdependent, so the terms of trade within any pair of states depend on the terms of trade they have with other states (Anderson 1979; Anderson and van Wincoop 2003). A warring state may divert resources previously used to produce certain exports in order to facilitate wartime production, thus reducing or cutting off those export flows. Conflict could result in decreased demand for the state's exports to the extent that demand is dependent on other trade flows interrupted by the conflict. Conflict may interrupt the supply of imports to the state to the extent it affects the supply chain for those imports. Finally, even when states do not directly trade with each other, indirect trade dependence increases the opportunity costs of a potential conflict between them because the uncertainty associated with war may cause their trading partners to seek other, more stable markets or suppliers (Polachek 1980; Gasiorowski and Polachek 1982; Crescenzi 2005; Maoz 2009).

The noncombatant mechanism. Indirect trade dependence also reduces the likelihood of conflict in a second way that has been undertheorized in the trade-and-conflict literature. Conflict creates costs for states that are not involved in it, but that are dependent on trade relations with the warring states. By interrupting trade flows, conflicts create negative externalities for nonparticipant states, including by decreasing their access to commerce, increasing the costs of their imports and decreasing the demand for their exports. These externalities are a type of spillover or neighborhood effect (Cornes and Sandler 1986). As a result, indirect trade dependence reduces the probability of conflict by increasing the incentives for third parties to attempt to prevent the conflict (for related arguments, see Dorussen and Ward 2008; Böhmelt 2009, 2010). While many states do not have the capability to significantly influence the potential combatants, others can and do use their power to deter wars that would damage international commerce (Gilpin 1981; Kindleberger 1986; Krasner 1999). Similar to the notion of social balance in a social network, where a person A may have an incentive to prevent a conflict between two of his or her friends, so too could a state A bear significant costs if two of its important trading partners (B and C) were to fight each other, thus giving A an incentive to prevent that conflict. Existing approaches to the relationship between trade and conflict have held that, if B and C trade little with each other, then trade would have little or no effect on their probability of conflict.

Both of these mechanisms operate across various levels of aggregation in the international system. A conflict between A and B may interrupt their trade relations with many of their trading partners, potentially creating costs for such partners. In addition, if these flows are interrupted, additional trading relationships that are dependent upon these flows may also suffer, thus creating costs for additional states. Before turning to a more detailed discussion of these dynamics, we first illustrate how a conflict between a pair of states may interrupt trade flows with other states using three stylized (nonexhaustive) triadic examples (see Figure 1 for illustrations of these examples). In the first example, suppose state A imports the same goods from states B and C, which have relatively little direct trade with each other. The indirect trade ties between B and C can reduce the probability of conflict between

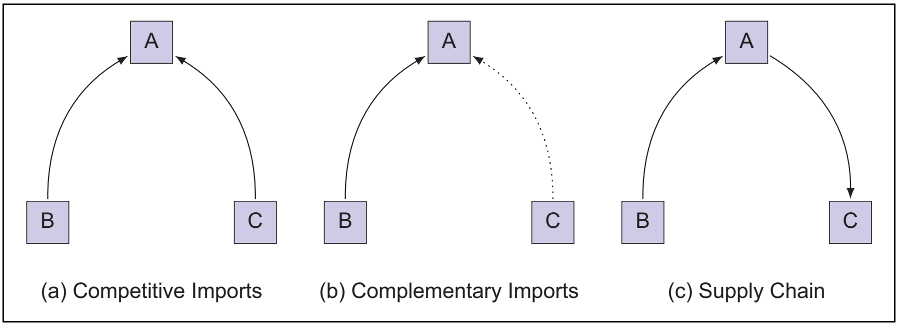


Figure 1. Illustration of the three triadic trade examples: (a) state A imports the same goods from states B and C; (b) state A imports complementary goods from states B and C; and (c) state A imports raw material from state B and exports manufactured goods to state C.

them in several ways. First, during such a conflict, B and C may choose to divert domestic resources away from producing their exports in order to produce weapons (or other goods that can be traded for weapons). If we assume that, prior to the conflict, trade and production decisions were made to maximize welfare, then these developments increase the cost of war for B and C. This could also disrupt A's supply of the applicable import, creating costs for A by negatively affecting its welfare, thus giving A an incentive to prevent the conflict. Second, it may be in A's interest to prevent B from taking over C, or vice versa. By maintaining multiple suppliers of the same good, A reduces the probability of collusion and thus reduces the price of its imports. Firms often prefer to import the same goods from suppliers in multiple countries to hedge against various types of "country risk." In practice, we may rarely observe conflict in examples such as this because A has an incentive to prevent it ex ante, and, knowing this, B and C may be less likely to initiate a conflict. Nonetheless, a potential illustration of this can be found by examining the modern history of Central America. Most Central American states trade relatively little with each other, but are heavily dependent on their mutual trade with the United States. The United States, in turn, has an incentive to prevent conflict between them to ensure minimal disruption to these trade relationships—indeed, the United States was instrumental in the establishment of many of these states partly because of commercial interests. Owing in part to this indirect trade dependence, there has been very little interstate conflict in Central America. The only recent exception is the El Salvador–Honduras "Soccer War," which ended after only four days following strong pressure from the US-led Organization of American States.

As a second example, suppose state A imports complementary goods from states B and C that A then combines to make an exportable good. Again, suppose that B and C trade relatively little with each other. Here, too, the indirect trade ties between B and C will work to reduce the probability that a conflict occurs between them. A conflict would interrupt the supply of imports to A, which could in turn interrupt its ability to export to others, giving A a strong incentive to prevent such a conflict. Second, A fears a takeover of C by B (or vice versa) because such a combination could create a more powerful (or even monopolistic) supplier to A, which could adversely impact A's terms of trade. Third, their joint trade with A also increases B's and C's opportunity costs of war, thus creating stronger incentives for them to resolve their dispute peacefully. Because they export complementary goods to A, both B and C know that if the other's supply to A is cut off, A may no longer have a demand for its own supply. Thus, both B and C know that, in the event of a conflict between them, not only would their direct trade with each other (which in this case is minimal) be cut off but also would their trade with A (and other third-party states in similar situations).

In the third example, state C imports a good from A that A manufactures using raw goods it imports from B. In this case, B and C have little direct trade, but trade indirectly via A. This indirect trading relationship would reduce the probability of conflict between B and C in two ways. First, A may attempt to intervene because a war between B and C has the potential to disrupt both the supply of A's imports and the demand for its exports. Indeed, because the two flows are codependent, a disruption in one is likely to disrupt the other. Second, the indirect trade relationship also raises the opportunity costs of war for B and C because a conflict between them is likely to disrupt their trade with A. A traditional dyadic approach to interdependence and conflict would have found that the small amount of trade between B and C would not have a significant effect in terms of raising their opportunity costs of war. This example therefore illustrates another way in which taking indirect trade relationships into account can reveal additional ways trade can affect the costs of war.

Trading Communities and Conflict

Thus far, we have explained two mechanisms by which conflict can interrupt trade flows in addition to those between the potential combatants and, in turn, how these indirect trade ties can reduce the probability of conflict. We have also illustrated how these mechanisms work in certain types of stylized triadic relationships. Yet, our argument provides no reason to think that these mechanisms operate only based on levels of triadic trade. Dorussen and Ward (2010) show, for example, that higher levels of triadic trade are associated with lower probabilities of conflict; yet, indirect trade may also reduce conflict within other structures. The question becomes in which type of structure or what level of aggregation we should expect these effects to operate most significantly. The existing work on extra-dyadic trade and conflict takes the important step of arguing that the location of states within the trade network matters; yet, it does not answer this question. In this section, we argue that the mechanisms by which indirect trade ties reduce the probability of conflict are most important within groups of states with relatively dense trade ties—or trading communities.

Both the combatant mechanism and the noncombatant mechanism operate in groups of states larger than a triad. Conflicts have the potential to interrupt many trade ties, both among the warring states and between those states and their trade partners. A conflict between A and B could cause interruptions to their trade with, for example, C, D, and E. All of C, D, and E would face negative externalities from a conflict between A and B. Also, the possibility of a conflict cutting off more of their trade flows with these third parties would increase the opportunity costs of war for A and B. Even other trade ties could be affected by the conflict. If trade between C and D relies on their respective ties to A and B, then this flow could also be adversely affected by a conflict that affects A–C and B–D trade. There are many potential ripple effects on trade of this kind within a complex network, and our intent here is not to describe them all.

Instead, our aim is to explain where these effects are most likely to be salient. In other words, in which situations are the disruptions to trade caused by conflict most likely to create the types of costs that, in turn, reduce the probability of conflict? In addition, how do we systematically account for the ways in which indirect, networked trade relations affect conflict behavior? Dorussen and Ward (2010) propose that we can systematically capture the effects of indirect trade ties using the concept of maxflow, particularly because it may be a good proxy for the information flow between the members of a dyad that is facilitated by their trading relations. The maxflow is the largest trade flow between two states that satisfies the following conditions: (a) the flow along any connection in the network is less than or equal to its trade capacity and (b) the flow entering a state along any connection is equal to the flow leaving it along all other edges incident on it. The maxflow is thus a useful concept for understanding the effects of the informational mechanism proposed by Dorussen and Ward (2010).

Yet, this concept does not capture other ways in which the networked structure of international trade may be relevant to the mechanisms we propose. We illustrate this point using the stylized exchange networks provided in Figure 2. In network 1, the maxflow between nodes 1 and 2 is equal to four because a connection can be made between 1 and 2 using four possible independent routes: 1-3-2, 1-4-2, 1-5-2, and 1-6-2. In Network 2, the maxflow between nodes 1 and 2 is also equal to four. The additional flows in Network 2 do not provide additional possible independent paths between 1 and 2. Thus, a theory based on the concept of maxflow would make equivalent predictions regarding the extent to which indirect trade ties between 1 and 2 would affect their conflict propensity in the two networks. Yet, the two networks vary in terms of density: Network 2 is significantly more densely connected than network 1. In terms of trade flows, network 2 can be thought of as more highly interdependent than network 1.

We argue that this difference between the two networks is crucial. The extent to which conflict affects trade in ways that create opportunity costs and negative externalities increases with the relative density of trade within a particular group of states. In a highly interdependent group, when individual trade flows are cut off

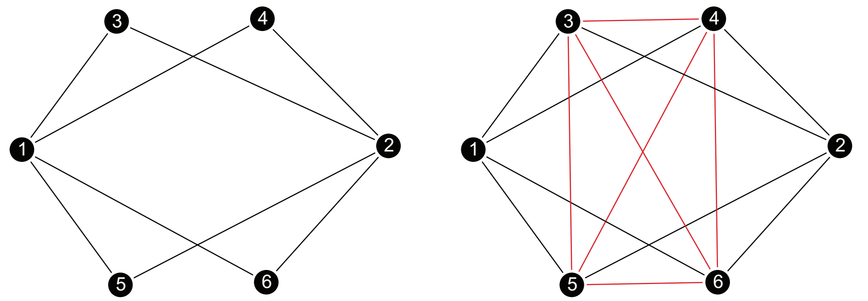


Figure 2. Two exchange networks. Network 2 is more densely connected than network 1.

by conflict among the group's members, the probability that this will adversely affect other flows is higher. Therefore, the costs of a conflict involving two member of such a group would be especially high. Preventing such a conflict may be difficult and costly itself, but the group's members will have particularly important incentives to overcome this collective action problem. By contrast, when the potential combatants are not embedded within a single group of highly interdependent states, fewer flows may be interrupted by the conflict, and thus the economic costs of the conflict would be significantly lower, all else equal. Here, the trade-disrupting effects of a conflict between two states may be so diffuse that their common trading partners would not have a sufficient incentive to overcome collective action problems and prevent the conflict. This type of scenario points to an important limitation on the mechanisms we have discussed: as the indirect trade dependence within a group of states becomes smaller (i.e., their collective trading relationships are more diffuse and less dense), the conflict-reducing effects of indirect trade are also smaller. Conversely, the effects of indirect trade dependence should be greatest in groups of states with relatively dense ties.

This argument points to the concept of the international subsystem, which scholars have long recognized is an intermediate and important level of analysis between dyads and the whole international system. The insights from the subsystems literature have been insufficiently incorporated into the trade-and-conflict literature. Several aspects of this literature are particularly important in this context. Most important is Deutsch's (1954) argument that mutual interdependence among groups of states causes them to form cohesive security communities. Similarly, Lake (1997) argues that, within subsystems, networks of interactions between states influence their behavior by creating local externalities. In addition, economic transactions are generally high within subsystems and low across them (Deutsch 1954; Dominguez 1971). Third, within each subsystem, individual states act as leaders and protectors of other states (Deutsch 1954; Holsti 1970). Finally, as Modelski (1961) argues,

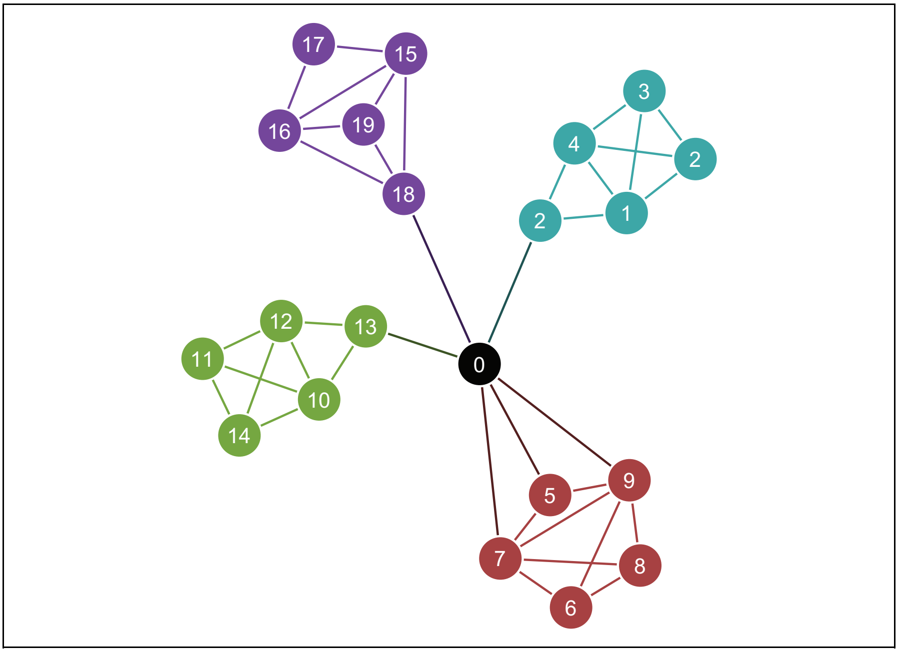


Figure 3. An exchange network with four trading communities.

"a subsystem in due course creates and maintains its own solidarity" (p. 151). Building on this work, others argue that the relationship between trade and conflict has important interactions with subsystemic characteristics defined by geography (Gleditsch 2003) and institutional ties (Mansfield and Pevehouse 2000).

Trade creates groups of states at the subglobal level in which the effects of indirect trade dependence are especially significant. Within these trading communities, states have many trading partners in common and, therefore, their dependence on each other is often far greater than their dyadic trade levels would suggest. Some dyads within a trading community trade significantly with each other, such as two developed states that trade differing manufactured goods they specialize in producing. Other dyads within a trading community may trade directly very little, however. This can occur, for example, when two states are at opposite ends of a single supply chain. Another example is of two states that are individually dependent on exporting and importing similar goods to and from the same third country. A stylized example of trading communities within an exchange network is provided in Figure 3. Four densely connected trading communities are clearly visible in the example, colored in red, green, blue, and purple. Some dyads within an individual community do not trade with each other, such as nodes 5 and 6. Node 0 is an interesting case because it trades with members of several trading communities. Yet, node 0 is more densely connected to the red community and would most likely be defined as belonging to that group.

The key factors that have shaped the structure of the global trading network are also responsible for the formation of trading communities. Trade flows highly unevenly across the international system, which is not at all surprising when taking economic factors into account (Gleditsch 2003). Geographic distance creates transaction costs that promote trade among close neighbors. This suggests that trading communities may have a strong regional component, although this may not always be the case. A state with a highly specialized production capability may be in the same trading community with a distant state that has a complementary demand for that specialized good. More generally, we would not always expect that a group of geographically clustered underdeveloped states would be in the same trading community. We can expect such states to trade relatively little with each other. Thus, if they export to and import from differing markets, they are likely to be in differing trading communities. Africa is a prime example. It would indeed be surprising to find that Africa consists of a cohesive trading community given that most states in the continent are poor and sell many of their raw goods to richer states outside the continent. Historical factors likely also contribute significantly to the formation of trading communities. We would expect, for example, that colonization and decolonization have had significant impacts on the structure of world trade, with former colonies continuing to trade significantly with their former colonizers. More recently, many of the trading relations established within the Soviet Union have continued among the former Soviet states, and thus we would expect a significant likelihood that these states are in the same trading community.

Within a trading community, the mechanisms by which indirect trade dependence reduces the probability of conflict are especially pertinent. A conflict between any dyad in the community is likely to disrupt many trade flows. The potential combatants stand to lose not only their direct trade flows but also many dependent trade flows with other community members. Thus, the opportunity costs of war for the potential combatants will be particularly large, even if they do not trade significantly with each other. In addition, because war is likely to interrupt some of their own trade flows with the combatants, the other members of the trading community face significant costs if they cannot prevent the conflict. Certainly, intervention may itself be costly, and in some cases costlier than the potential conflict. Yet, we argue that this is not always the case, and that in many cases the other members of the trading community will have the incentive to prevent a conflict from breaking out or intervene to stop it if it does. The potential combatants should also anticipate this strategic response from the other members of their trading community and therefore be more likely to find a peaceful resolution to their dispute. These arguments lead to the principal hypothesis of this article:

Hypothesis 1: The probability of conflict is lower between state dyads that are members of the same trading community.

Defining and Measuring Trading Communities

The structure of international trade is best conceived of as a network. In keeping with the recent work on indirect trade relationships, we use network theory and methods to analyze the effects of trading communities on conflict. Network theory provides a range of ideas about the ways in which ties between actors affect the structure of a system and, in turn, affect actors' behaviors (Hafner-Burton, Kahler, and Montgomery 2009). Network analysis methods allow analysts to describe structures, measure their properties and those of individual actors, and use these measurements to test hypotheses about the relationships between actors and structures.

The Trade Network

The first step in testing our hypothesis is to construct the international trade network, which we do using the data provided by Gleditsch (2002). Constructing this network requires us to assign weights to the dyadic ties between states, which we do using the trade flows between them. Specifically, we define these weights using the formula for dyadic trade dependence provided by Oneal and Russett (1997) and used by much of the literature on which we build:

$$w_{t,ij} = \frac{x_{t,ij} + m_{t,ij}}{\mathrm{GDP}_{t,i}}, \tag{1}$$

where $x_{t,ij}$ is the total exports from country i to country j in year t, $m_{t,ij}$ is the total imports to country i from country j in year t, and $\mathrm{GDP}_{t,i}$ is the total gross domestic product (GDP) of country i for year t.

Community Detection

The more complex aspect of our research design is defining the trading communities within the international trade network. The traditional approach in the subsystems literature has been to define these groups based on common membership in a geographic region or institution. Not only would such an approach create threats to inference from a research design perspective, it is not a plausible way of operationalizing our definition of trading communities. Instead, we use the network analysis tool of community detection to determine which states are in which trading communities. Defining and detecting communities in networks is not trivial. The number of possible sets of communities (also known as network partitions) is enormously large. Even if we were to assume that only two trading communities existed (which we do not) we would have over 10^{57} possible partitions of the global trade network of 192 states. The challenge is to use a method that detects and defines trading communities in a way that is both methodologically rigorous and produces results that are substantively meaningful.

Methodologists have developed several methods for performing community detection, such as hierarchical clustering, spectral clustering, blockmodeling, LS-sets, and clique percolation (cf. Porter, Onnela, and Mucha 2009; Fortunato 2010). The most promising method, however, is that of modularity maximization developed by Newman and Girvan (2004), which appears to detect communities that are substantively meaningful over a wide range of network types (Newman and Girvan 2004; Guimerà and Amaral 2005; Guimerà, Turtschi, and Amaral 2005; Blondel et al. 2008; Waugh et al. 2009). Applied to the trade network, a modularity optimization algorithm attempts to maximize the extent to which states defined as being in a given community trade with each other and minimize the extent to which they trade across communities. Thus, modularity measures how well-separated communities are from each other in the network—in other words, the extent to which the communities are modular.[2] This method has recently been applied in many recent studies of American politics, including studies of Congressional committee membership (Porter et al. 2005), roll-call voting (Waugh et al. 2009), and bill cosponsorship (Zhang et al. 2008). In the international relations context, similar methods have been used to analyze communities of states based on a network of alliance ties (Traag and Bruggeman 2009), communities in the network of case citations by the European Court of Human Rights (Lupu and Voeten 2012), communities in the United Nations General Assembly (UNGA) voting network (Macon, Mucha, and Porter 2011), and communities in multicommodity trade networks (Barigozzi, Fagiolo, and Mangioni 2010). Details on how we maximize modularity are in the appendix.

Modularity maximization has several important benefits in this context. The first is its ability to allow us to systematically account for borderline cases. While we expect that many states will clearly belong to one trading community or another, it is also likely to be the case that many will be borderline cases, perhaps by virtue of being heavily trade dependent on two groups of states that trade relatively little with each other. The modularity maximization algorithm produces slightly different results each time it is run because there are many local maxima at which modularity is optimized. This is, in part, because of states that straddle the borders between two or more communities. By running the algorithm many times, we are able to learn how to classify these borderline cases, as we explain in the hypothesis testing section.

Second, modularity maximization allows us to detect communities at various levels of aggregation. In any network, communities can be conceived of at various levels, often with smaller levels of communities "nested" within larger ones. For example, in networks of academic citations, communities can be detected at the level of a whole field (because, e.g., political science papers cite each other more often than they cite economics papers) or at the level of a subfield (because, e.g., international relations papers cite each other more often than they cite comparative politics papers). Using a similar intuition, Buzan and Waever (2003) discuss how the world system can be broken down into security complexes and subcomplexes. We recognize that, much like the terms *regional subsystem* and *security community*, our concept of *trading community* contains some ambiguity, particularly in terms of size (see also Aggarwal 1985). Yet, in terms of operationalization, this ambiguity is an

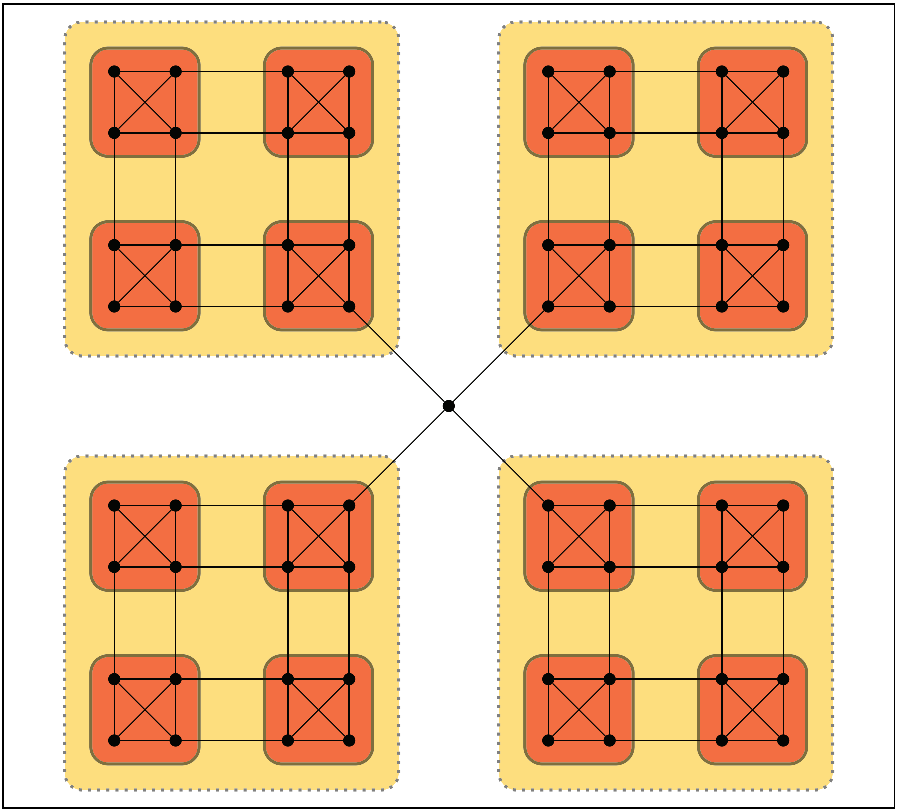


Figure 4. A hypothetical network. At lower resolutions, we detect the large communities displayed in yellow, while at higher resolutions we detect the smaller orange subcommunities.

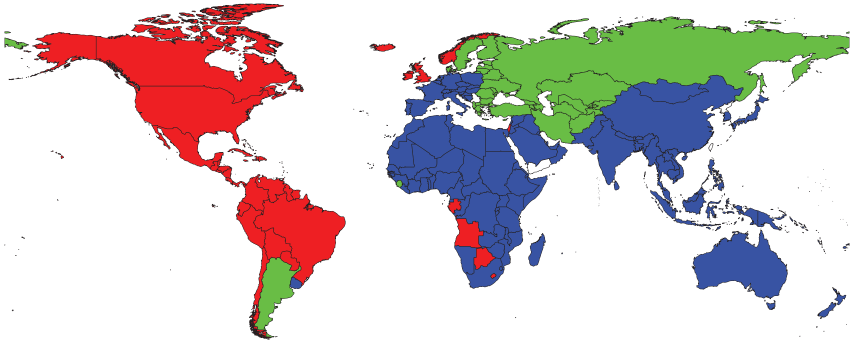
advantage when we use modularity maximization to define the communities. Our theory does not suggest a specific number of trading communities nor does it suggest how large they are. We could certainly choose to make an ex ante argument regarding the size and number of trading communities, but then our hypothesis testing results would be valid only to the extent this ex ante argument is valid. Instead, we have opted not to predefine these parameters, but rather to demonstrate the range of trading community sizes over which our theory holds. We do this by varying the resolution parameter in the modularity maximization algorithm, a process we explain further in the appendix.

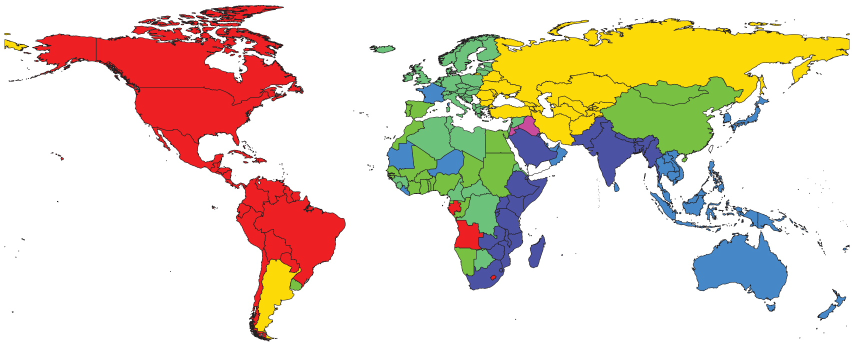
We use Figure 4 to illustrate the intuition behind community detection, modularity maximization, and the resolution parameter. Visually, the network seems to consist of four large communities, each of which has four smaller communities embedded within it. While there are connections reaching across these communities, the bulk of the connections are concentrated within them. At a low resolution level, we would maximize modularity by defining community members in accordance with the four large clusters in yellow (and surrounded by dotted lines). When the resolution parameter is sufficiently large, however, we would detect the sixteen smaller communities in orange.

Our measurement strategy ultimately cannot be used to determine with absolute certainty which partition defines the "true" set of trading communities. While this issue is significant, this would be the case for any other qualitative or quantitative measurement method we could use to define the communities, which would always be subject to potential arguments about levels of aggregation and borderline cases. Our aim here is not, therefore, to argue that one or another set of trading communities is the correct one, but to test our hypothesis over a range of alternate plausible ways of defining them.

We use modularity maximization to define trading communities at an annual basis over a range of resolutions. Figure 5(a) through (c) show representative partitions for the year 2000 using resolutions levels that yield three, seven, and fourteen trading communities (color versions available online). At a relatively low resolution level, we observe three large trading communities. One community includes the bulk of the Western Hemisphere in what appears to be a US-centric community. In 2000, Argentina significantly devalued its currency, causing short-term changes in its trade relations. In previous years, Argentina was a member of the Western Hemisphere trading community. A few states outside the Americas are also members of this trading community, notably the United Kingdom and Israel, a finding likely driven by their close trade ties with the United States. Others, such as Norway, Iceland, and Ireland, have less significant trade ties with the United States, but do have close ties with the United Kingdom, suggesting that they are in this community largely because the United Kingdom is also. The second large community we see at this resolution level includes the former Soviet Union, Eastern Europe, and parts of the Middle East. Finally, the rest of the world belongs to a trading community that includes Japan, China, India, much of Europe, Southeast Asia, and most of Africa. This is arguably the most surprising among the findings at this level of resolution because it includes several major economies that are geographically dispersed. The surprising nature of this result suggests, in fact, that the trading community defined at this resolution level is actually an amalgamation of several subcommunities.

As the resolution level increases, so does the number of trading communities defined. Figure 5(b) shows a partition with seven communities. The Western Hemisphere community remains largely intact, which is not surprising given the level of dependence of most of these states on US trade, and vice versa. Nonetheless, at this resolution level, the United Kingdom is no longer part of the Western Hemisphere community, and instead belongs to a smaller community consisting of Northern and Central Europe along with several of their African trading partners. We noted earlier that countries such as Norway, Iceland, and Ireland were likely only defined as being in the Western Hemisphere community by virtue of their trade with the United Kingdom, so it is not surprising to observe that they "follow" the United Kingdom into


(a) Low resolution


(b) Medium resolution

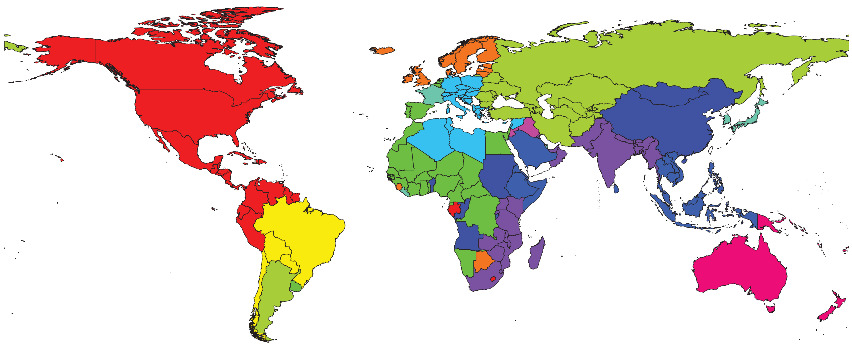

(c) High resolution

Figure 5. Trading communities in 2000.

this smaller community. Other states, such as Sweden, Finland, and Denmark, are now defined as being in this community despite having previously been defined as part of the larger Russia-centered community rather than the Western Hemisphere community. This suggests that, at the lower resolution level, these countries are borderline cases; indeed, several other partitions at the low resolution level include these in the same community as the United States and the United Kingdom. Aside from these states, the community of former Soviet Bloc states remains whole at this resolution level. The only former members of the Soviet Union not in the latter community are the Baltic states, a finding that is not surprising given that these economies have distanced themselves from Russia more so than any others. The largest community found in the low resolution level breaks into several communities at this level. The most notable of these are trading communities that include (1) China and many of its smaller trading partners; (2) Southeast Asia, Australia, and Japan; and (3) many states bordering the Indian Ocean, including South Asia and East Africa.

Finally, at a higher level of resolution, we observe several new trading communities. Three changes relative to the medium resolution are worth noting. First, Northern Europe and Central Europe seem to have split into two communities at high resolution. Second, several states in South America, most notably Brazil, form a subcommunity within the larger Western Hemisphere community. Finally, Australia, New Zealand, and several of the Pacific Island states have separated from Southeast Asia into a smaller trading community that is most likely driven by Australian trade ties. A large proportion of global trade is conducted within trading communities. At a low level of resolution, most global trade has been conducted within the trading communities. Interestingly, the percentage of global trade conducted within these large communities decreased from about 90 percent in 1960 to about 55 percent in 2000, which suggests that globalization may have evened out global trade flows to a significant extent. At the medium level of resolution, approximately 40 percent of trade is conducted within trading communities, despite the fact that only approximately 20 percent of dyads are members of the same trading communities. This result means that a disproportionately large percentage of global trade is conducted within these groups. Finally, at a high level of resolution, approximately 30 percent of trade is conducted within the 15 percent of dyads that are joint members of these small subgroups.

Hypothesis Testing

To test our hypothesis, we first create a variable that indicates whether, in a particular year, both members of a dyad were members of the same trading community (SAME TRADING COMMUNITY). As noted previously, the modularity maximization algorithm produces slightly different results each time it is run at a given resolution because there are many local maxima at which modularity is optimized. The network analytic literature provides little guidance on how to choose among such partitions. We could certainly choose one that appeared to have high face validity and test our hypothesis using it, but the validity of our results would then depend on the validity of that particular partition. Instead, we use a construction that takes advantage of this feature of modularity maximization. For each resolution level, we run the modularity maximization algorithm 100 times. In each partition, we recognize that there is a certain degree of uncertainty regarding whether states have been correctly classified into trading communities. By running the algorithm many times, we iteratively learn more about the classification and reduce this uncertainty. Thus, for example, if state A appears in a particular community that includes state B in 90 of the 100 partitions, it is more likely than not that state A belongs in that community. For each dyad-year, we therefore code Same Trading Community as "1" if it appears in the same trading community in more than 50 percent of the partitions and "0" if it does not.

We use Zeev Maoz's construction of dyadic militarized interstate disputes (MaozMID) as the dependent variable (Gochman and Maoz 1984; Jones, Bremer, and Singer 1996). We coded the variable as "1" for dyad-years in which there was an onset of a militarized interstate dispute in which force was threatened or used, and "0" otherwise. We modified the coding of MaozMID such that it indicates whether a MID was initiated in the year following the year in question, which has the same effect as lagging all of the independent variables by one year. Because we argue that Same Trading Community should have a negative, significant relationship with MaozMID regardless of the level of direct trade dependence, we control for this (Dyadic Trade Dependence Low) using the same formula used to calculate the weights in the trade network (Oneal and Russett 1997). We include this control in model 1 and remove it in model 2 to demonstrate that our primary result is robust to the inclusion and exclusion of this measure. We also control for the maxflow (MaxFlow), to capture some of the indirect effects informational mechanisms may have on conflict propensity. If Same Trading Community has a significant relationship with MaozMID despite the inclusion of these controls, this would provide evidence that the clustered structure of the trade network has an important relationship with conflict in ways not previously understood.

We also include several other controls that may affect the propensity for dyadic conflict and that have been used in much of the trade-and-conflict literature (Oneal and Russett 1997; Gartzke 2007; Dorussen and Ward 2010). Democratic peace theorists argue that democracies have a lower propensity for conflict, especially with each other (Doyle 1986; Bremer 1992, 1993; Maoz and Russett 1992, 1993; Ward and Gleditsch 1998). We therefore control for the lower (Democracy Low) and higher (Democracy High) democracy scores in the dyad using the Polity IV data (Marshall and Jaggers 2002). Shared membership in intergovernmental organizations (IGOs) may reduce the probability of conflict (Russett, Oneal, and Davis 1998; Dorussen and Ward 2008), so we control for the number of shared IGOs memberships in the dyad using the Correlates of War (COW) 2 International Governmental Organizations Data (Pevehouse, Nordstrom, and Warnke 2004). Economic development may affect conflict propensity, so we follow Gartzke (2007) and others in controlling for the lower of the GDP levels in the dyad-year. We also control for the effects of monadic power on the probability of conflict. The most powerful states are more actively engaged in interstate relations and may therefore be more likely to fight wars. We therefore include a dichotomous variable (MAJOR POWER) coded "1" for dyads in which at least one member is one of the five post–World War II major powers (i.e., United States, USSR/Russia, United Kingdom, China, and France). Allied states may be less likely to fight each other, so we include a dichotomous variable (ALLIANCE) coded "1" for dyads that have concluded an entente, neutrality pact or defense pact based on the COW Alliance Data Set (Singer and Small 1966; Small and Singer 1990). States may be more likely to attack weaker opponents. We therefore control for the natural logarithm of the ratio of the stronger state's COW capabilities index to that of the weaker state (CAPABILITY RATIO).

We control for several geographic factors known to affect the propensity of dyadic conflict. Including geographic controls allows us to conduct a particularly strict test of the relationship between trading communities and conflict given that we know trading communities are clustered geographically. Wars are generally less costly for states to conduct against their immediate neighbors, so we construct a dichotomous variable coded "1" for dyads that share a land border or that are separated by less than 150 miles of water (CONTIGUITY). We also include a control measuring the natural logarithm of the distance between national capitals (DISTANCE). We adopt the Beck, Katz, and Tucker (1998) method of including temporal spline variables and a measure of the duration of dyadic peace (PEACEYEARS) to control for duration dependence. Dyad-years with ongoing MIDs are excluded to address problems of serial correlation. Our analysis includes the years 1960 to 2000.

Using this model, we tested our hypothesis over a large range of community detection resolutions. Table 1 provides the results of these models for resolutions yielding three (low), seven (medium), and fourteen (high) trading communities. The results provide substantial support for our hypothesis. States that are members of the same trading community are less likely to experience militarized disputes with each other. Just as importantly, these results are consistent whether or not we take into account the extent to which those states are directly dependent on each other in terms of trade. This means that the pacific effects of trade that result from joint membership in a trading community do not depend on the extent of direct trade dependence, which is the key explanatory variable in extant theories of trade of conflict.

The control variables generally have the expected relationships with conflict and are consistent with the results of studies using similarly specified models (Oneal and Russett 1997, 1999; Gartzke 2007). Consistent with Dorussen and Ward (2010) , we find that Democracy Low is associated with a lower probability of conflict. Interestingly, unlike existing studies, we find that dyadic alliance relationships do not have a

Table 1. Logit Models of MaozMIDs.

	Low Resolution		Med. Resolution		High Resolution	
Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Same trading community	−0.305*** (0.086)	−0.322*** (0.086)	−0.172* (0.086)	−0.201* (0.086)	−0.205* (0.091)	−0.244** (0.091)
Dyadic trade dependence low	−11.289 (7.830)	—	−11.336 (7.931)	—	−10.822 (7.776)	—
MaxFlow	−.193 (0.317)	−.337 (.317)	−.188 (.316)	−.331 (.316)	−.185 (.316)	−.318 (.317)
GDP High	.133*** (.037)	.155*** (.034)	.141*** (.037)	.163*** (.034)	.139*** (.037)	.160*** (.034)
GDP Low	.113*** (.032)	.098** (.031)	.111*** (.032)	.095** (.031)	.110*** (.032)	.096** (.031)
Democracy High	.030** (.012)	.029* (.011)	.028* (.011)	.027* (.011)	.028* (.011)	.027* (.011)
Democracy Low	−.136*** (.017)	−.141*** (.017)	−.135*** (.017)	−.139*** (.017)	−.135*** (.017)	−.140*** (.017)
Shared IGO Memberships	.007 (.004)	.006 (.004)	.007 (.004)	.006 (.004)	.007 (.004)	.006 (.004)
Contiguity	2.694*** (.175)	2.694*** (.176)	2.698*** (.175)	2.702*** (.176)	2.707*** (.176)	2.713*** (.177)
Distance (logged)	−.185*** (.019)	−.182*** (.019)	−.182*** (.018)	−.179*** (.018)	−.182*** (.018)	−.179*** (.018)
Major Power	.797*** (.127)	.752*** (.122)	.794*** (.128)	.745*** (.123)	.792*** (.128)	.744*** (.123)
Alliance	.038 (.112)	.007 (.110)	.044 (.112)	.016 (.110)	.047 (.112)	.022 (.110)
Capability Ratio (logged)	−.124*** (.031)	−.123*** (.030)	−.126*** (.031)	−.125*** (.031)	−.127*** (.031)	−.125*** (.031)
Peaceyears	−.338*** (.027)	−.339*** (.027)	−.336*** (.027)	−.337*** (.027)	−.336*** (.027)	−.337*** (.027)
Constant	−6.116*** (.299)	−6.173*** (.297)	−6.312*** (.291)	−6.373*** (.288)	−6.295*** (.291)	−6.349*** (.289)
N	390,914	390,914	390,914	390,914	390,914	390,914
χ^2	5814.79***	5802.00***	5790.01***	5777.18***	5819.69***	5806.64***

Note. *p < .05. **p < .01. ***p < .001.
Robust standard errors in parentheses.
Resolutions correspond to three, seven, and fourteen trading communities. Estimates for three temporal spline variables are not reported.

significant relationship with conflict. Taking only dyadic trade dependence into account, allies are less likely to fight wars, as Oneal and Russett (1997) and Gartzke (2007) found. However, when we also account for indirect trade dependence by including trading community membership in the model, allies are no less likely to fight than nonallies. This result suggests that trading community membership explains conflict behavior to a sufficient extent as to obscure the effects of direct alliance ties. In other words, it may be the case that indirect trade ties drive the significant relationship between alliances and conflict found in other studies, a possibility we hope to further explore in future work.

In addition to the results reported in Table 1, we used a model identical to model 1 to test our hypothesis over other resolution levels. At all resolution levels between three and fifteen trading communities, we find that Same Trading Community has a significant ($p < .05$), negative relationship with MaozMID, which indicates that, within a significant range, our results do not depend on the resolution level we specify. In other words, if we view the world as consisting of three very large trading communities, such as those defined in Figure 5(a), then joint membership in these communities is associated with a lower probability of conflict. Yet, even if we take those communities and divide them into subcommunities, such as those defined in Figure 5(c) (and even slightly smaller ones), joint membership in these smaller groups continues to be associated with a lower probability of conflict. We also follow Dorussen and Ward (2010) in testing whether our results are consistent when we examine only "politically-relevant dyads," that is, those that are either contiguous or include at least one major power. For this sample, we found that Same Trading Community has a significant ($p < .05$) and negative relationship with MaozMID for the same range of levels of aggregation as reported above (i.e., three to fifteen trading communities).

Our results therefore demonstrate that across a broad range of plausible sizes of trading communities, dyads within these communities have a lower probability of conflict. Nonetheless, our results also indicate that at certain levels of aggregation, this result may not hold. When we define trading communities at particularly large levels of resolution (i.e., more than fifteen communities), we find that joint membership in such groups is not significantly associated with a lower probability of conflict. In such small groups, there may not be sufficient (or any) members with the capacity to pay the costs of preventing a potential conflict. Similarly, when we define the world as consisting of only two trading communities, we also find that joint membership in such groups is not significantly associated with a lower probability of conflict. In groups this large and diverse, the trade disruptions that may be caused by a potential conflict may be sufficiently diffuse such that the group's members are not capable of overcoming the collective action problem of preventing the conflict. These results therefore suggest that, while the relative density of trade ties is an important predictor of conflict, this factor interacts with group size in ways that merit further investigation.

Conclusion

This article is primarily intended to incorporate the complexity of interdependence into the study of trade and conflict. We make two contributions at the theoretical level. First, we explain how indirect trade ties decrease the probability of conflict by increasing the costs of war both for the potential combatants and for their commercial partners. This allows us to recognize the situations in which even states that trade relatively little with each other may be impacted by the pacific effects of trade, a possibility the existing literature has overlooked. Second, we bridge a gap between the interdependence and subsystems literatures by explaining how indirect trade ties create highly interdependent trading communities within which conflict is less likely. Scholars have recognized that there is an important connection between globalization and regional security (Buzan, Waever, and de Wilde 1998; Buzan and Waever 2003). Because we find that trading communities are geographically clustered, our argument suggests that indirect trade dependence is a key factor in the relationship between globalization and regional security.

We find that states within the same trading community are significantly less likely to experience conflict with each other. This effect is both robust and relatively large. We do not specify the number and size of trading communities ex ante, but rather determine the range of these values over which our hypothesis is supported. We find such support over a large range of possible ways of defining the size and quantity of trading communities, suggesting that the effects of indirect trade dependence operate at various levels of aggregation within the international system. Just as importantly, this effect is consistent even when we control for the level of dyadic trade dependence, providing evidence that membership in trading communities (and indirect trade dependence more generally) reduces conflict in ways not captured by traditional analyses that focus strictly on dyadic trade ties.

Our argument suggests additional ways in which the relationship between indirect trade relations and conflict could be analyzed. First, we have argued that the density of a dyad's common trade relations has significant effects on their conflict propensity. This is why joint membership in a trading community, a group defined in terms of relative density, is the key variable in our analysis. If the density of common trade relations has these effects, moreover, our argument suggests that these conflict-reducing effects should increase with the density of the trading community. As a result, relatively dense trading communities may be less conflict-prone than other trading communities. An in-depth examination of this implication is outside the scope of this article, although in the future we hope to construct a model using a community-level unit of analysis that would allow us to test it. Second, as noted above, the networks approach suggests some ways in which the complex causal relationship between trade and conflict could be further explored. If, as we argue, indirect trade ties affect the probability of conflict and if, as others argue, direct trade relationships are affected by the probability of conflict, then it may also be the case that conflict affects indirect trade ties. We have discussed some examples of how this may occur and hope to explore others in future work.

From an empirical and methodological perspective, our article makes an important contribution to the trade-and-conflict literature by demonstrating how network analytic tools can be used to improve our ability to analyze complex interdependence. This methodological approach also represents a significant step forward for studies of international subsystems. A key challenge in that literature has always been rigorously defining subsystem. Thompson (1973), for example, found twenty-two differing definitions of regional subsystems in the literature up to that date, a number that has increased with the recent attention to this topic (Lake 1997). Buzan and Waever (2003) note that the problem of definition was a key cause of what they call the failure of the regional subsystems literature of the 1960s and 1970s. Communities, blocs, and other subsystems have traditionally been defined using some combination of qualitative evidence, geographic proximity, and institutional ties. While such evidence is important in defining certain types of subsystems, it has generally been relied on unsystematically, leading to debates over the boundaries of subsystems that distract us from more interesting questions such as how subsystems form and how they affect state behavior. Modularity maximization offers us the ability to define international subsystems in a way that systematically accounts for the uncertainty regarding borderline cases and levels of aggregation. This, in turn, allows us to focus our analysis on the question of how subsystems affect behavior and away from the descriptive question of which state belongs in which group. We hope, therefore, that this article serves as a guideline for the systematic analysis of various types of international subsystems.

Appendix

Modularity Maximization

In this appendix, we explain the formal definition of modularity and the algorithm we use to maximize it. Assume we are given a graph (or network) $G = (V, E)$ with n nodes (or vertices) V and m links (or edges) E, with weights w_{ij} on the links. The edges in this network are directed, meaning they are asymmetric (i.e., state A's trade dependence on state B may be different from state B's trade dependence on A). The $n \times n$ adjacency matrix of the graph G can then be defined as $A_{ij} = w_{ij}$ whenever there is a directed link (ij), and $A_{ij} = 0$ otherwise. The incoming degree of a node i (i.e., the number of nodes that connect to node i) is denoted by $k_i^{\text{in}} = \sum_j A_{ji}$ and the outgoing degree (i.e., the number of nodes to which node i connects) by $k_i^{\text{out}} = \sum_j A_{ij}$.

Assume each node i is assigned to a community σ_i. The modularity of such a partition can be defined as

$$Q(\{\sigma\}) = \sum_{ij} (A_{ij} - \gamma p_{ij}) \delta(\sigma_i, \sigma_j), \tag{A1}$$

where $\delta(\sigma_i, \sigma_j) = 1$ if and only if $\sigma_i = \sigma_j$, that is, where i and j are in the same community (Newman and Girvan 2004; Reichardt and Bornholdt 2006). Let p_{ij} be an expectation value of an ij link that is taken to be

$$p_{ij} = \frac{k_i^{\text{out}} k_j^{\text{in}}}{m}. \tag{A2}$$

for a directed network (Leicht and Newman 2008). This p_{ij} is used to compare a random null model to the empirical trade network, in this case with similar degrees. Other null models have also been suggested to deal with, for example, bipartite graphs (Barber 2007) and negative weights (Traag and Bruggeman 2009).

The parameter γ is the so-called resolution parameter, introduced by Reichardt and Bornholdt (2006), which allows analysts to detect communities at various levels of detail. Larger values of γ correspond to relatively smaller communities and lower γ to relatively larger communities. It is possible, in one extreme (as $\gamma \to \infty$), to specify a resolution level so high that modularity is maximized by defining each country as a separate community. At the other extreme (as $\gamma \to 0$), we could define it such that there is only one global community. Of course, under either extreme we would not be able to reject the null hypothesis, but neither of these would be a meaningful operationalization of our theory. In Table 1, the partitions we describe as having low, medium, and high resolution have values of γ of 0.6, 1.1, and 1.7, respectively. We have separate trade networks for each year, and we would like to consider them all at once, similar to the multislice modularity provided by Mucha et al. (2010). Consider the graph $G = (V, E_1, E_2, \ldots, E_T)$, where $E_1, \ldots, E_T$ the represents the links at time $1, \ldots, T$ between the nodes V. We denote by $A_{t,ij}$ the associated adjacency matrix for each ij link at time t. The modularity formula as given in Equation A1 can then be extended slightly to yield

$$Q(\{\sigma\}) = \sum_t \sum_{ij} (A_{t,ij} - \gamma p_{t,ij}) \delta(\sigma_{t,i}, \sigma_{t,j}), \tag{A3}$$

where $\sigma_{t,i}$ now represents the community of node i at time t.

Over the past few years, many algorithms for optimizing modularity have been suggested (for an overview see Porter, Onnela, and Mucha 2009; Fortunato 2010). Because the problem is NP-hard (Brandes et al. 2006) it is unlikely that there is an efficient algorithm to solve the optimization problem perfectly. Numerous heuristic algorithms have been suggested, however, such as eigenvector optimization (Newman 2006), extremal optimization (Duch and Arenas 2005), and simulated annealing (Guimerà and Amaral 2005; Reichardt and Bornholdt 2006). Most of these methods, however, are unable to handle large amounts of nodes in a reasonable time. For addressing the resolution issue, for example, we run the algorithm repeatedly, thereby limiting the number of algorithms to choose from.

There are, however, some algorithms that are both efficient (i.e., they run in almost linear time) and effective (i.e., they can correctly identify communities in test settings; Lancichinetti, Fortunato, and Radicchi 2008; Lancichinetti and Fortunato 2009). The so-called Louvain method developed by Blondel et al. (2008) is especially suitable for optimizing modularity. In brief, the Louvain method works as follows. We start out by assigning each node to its own community, such that at the start there are as many communities as there are nodes. We loop (randomly) over all nodes and add them to a community that increases the modularity as much as possible. Then we form a new graph in which each node represents the communities found at the previous level, with links between these new nodes representing the weights between each community in the old graph. In this way, smaller and smaller graphs are obtained, with nodes representing communities (and possibly subcommunities). The algorithm ends when modularity can no longer be increased. In the following, we define this more technically.

Formally, the algorithm works by first removing node i from its community, and then calculating the effect on the modularity measure of adding node i to a community—possibly the same one. The effect on modularity of putting node i in community r in time t can be written as

$$\Delta Q(\sigma_{t,i} \to r) = \sum_t (m_{t,ir} + m_{t,ri}) - ([m_{t,ir}] + [m_{t,ri}]), \tag{A4}$$

where $m_{t,ir} = \sum_j A_{t,ij}\delta(\sigma_{t,j}, r)$ denotes the total weight from node i to community r, with $m_{t,ri}$ defined similarly, and $[m_{t,ir}] = \sum_j p_{t,ij}\delta(\sigma_{t,j}, r)$ the expected weight from i to r with again $[m_{t,ri}]$ defined similarly. Each node is then added to the community for which this effect on modularity is maximal.

After we have completed the first level, we aggregate the communities into nodes for a new graph, and define the weight of the links between these new nodes dependent on the communities. Considering communities r and s, the total weight from communities r to s can be (with a bit of abusive notation) written as $m_{t,rs} = \sum_{ij} A_{t,ij}\delta(\sigma_{t,i}, r)\delta(\sigma_{t,j}, s)$. Using this as the weight of the link between node r and s in the new network, the expected value of this link can then be written as

$$p_{t,rs} = \frac{k_{t,r}^{\text{out}} k_{t,s}^{\text{in}}}{m_t} \tag{A5}$$

$$= \sum_{ij} A_{t,ij}\delta(\sigma_{t,i}, r) \sum_{ij} A_{t,ij}\delta(\sigma_{t,j}, s) \frac{1}{m_t}, \tag{A6}$$

which is exactly the expected value of the links between communities r and s in the old network. Hence, joining nodes r and s in the new network corresponds to joining communities r and s in the old network. Doing so for all type of links then gives us a correct new network, upon which we can iteratively apply the method described previously. We stop the procedure if we can no longer increase modularity. Repeating this algorithm, and thus iterating this loop in random order over the nodes, results in slightly different partitions each time.

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Notes

1. Earlier work found no significant relationship between trade and conflict (Keshk, Pollins and Reuveny 2004; Kim and Rousseau 2005) but Hegre, Oneal, and Russett (2010) argue that these results were due to model misspecification.
2. Although the technology did not exist at the time, Deutsch (1957) captured some of the same intuition these methods rely on: "[T]he existing network of international trade is the most striking evidence we have of real economic ties within the North Atlantic area. If we calculate for each country in the area the top two countries to which it exports and the top two countries from which it imports, we find that the flow is to and from other countries within the North Atlantic area almost exclusively. The ties are much stronger among North Atlantic countries than with outside areas" (p. 145).

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