Trade and War:
A Global Input-Output Network Perspective*

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Abstract

We build a model linking positions of two states in a global input-output production network to their bilateral probability of military conflict. The model embeds an Armington-Long-Plosser trade framework into a bargaining setting with incomplete information, where both sides can observe expected wartime damages determined by network architecture but do not observe their opponents' outside options. We show that bilateral network exposures of real GDP to war disruptions are crucial determinants of optimal bargaining strategies, which in turn affect probabilities of war. We demonstrate that it is not just the degree of trade openness that affects probabilities of war; relative network positions also matter. In particular, higher asymmetry in mutual network dependence can reveal information and reduce odds of conflicts. We test our theoretical prediction by combining the Correlates of War project data and the World Input-Output Table during the 1965-2014 period. Our logit regression results support the theoretical predictions.

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1 Introduction

Does increased interconnectedness promote peace? Historical evidence is mixed. While European trade integration has been credited for preventing a repetition of the two world wars, the Ukraine-Russia conflict has reignited concerns about relying on potential ideological or territorial adversaries for supplies of intermediate goods. Moreover, such concerns are not limited to bilateral trading considerations, changes in network connections of any one trading partner may change patterns of mutual dependence to a certain degree in an interconnected global network, and consequently affect probabilities of war. Those issues call for a global network perspective on military conflicts. In this paper, we address the following questions: How does the global input-output network relate to bilateral probabilities of conflicts? What features of the network matter? Is there empirical evidence that supports the role of production networks in affecting probabilities of war?

We build a model that explicitly relates the global input-output network to bilateral probabilities of war, conditional on two states entering a bargaining process. To our knowledge, our paper is the first to establish such a micro-founded linkage. We show that bilateral network exposures of real GDP to war disruptions are crucial determinants of optimal bargaining strategies, which in turn affect the probabilities of war. Due to differing connectivity patterns within the global network architecture, two states may exhibit symmetry or asymmetry in their network exposures. We extend Compte and Jehiel's (2004, 2009) incomplete information bargaining framework to accommodate negotiations between two states with arbitrary degrees of asymmetry in their network positions. We argue that it is not just the degree of interconnectedness that affects the probabilities of war; relative network positions of two states, which reflect the full architecture of global network structure, also matter. We provide empirical evidence that supports the role of network structures, in particular, the importance of asymmetry in mutual network dependence, in affecting probabilities of conflicts. By capturing the importance of such network induced heterogeneities both theoretically and empirically, our paper introduces a global input-output network perspective into the theoretical modeling of military conflicts.

We use an Armington (1969) model that features input-output linkages among a set of states in the spirit of Long and Plosser (1983). In our model, states are interconnected through both the global production network and a structure of demand compositions that captures each state's demand for final goods produced in other states. We model military conflicts primarily as disruptions to trade routes that push up iceberg trading costs between the two warring states, and between them and their third party trading partners. Although military conflicts may involve loss of labor force, which our model allows, economic costs arising from trade disruptions have long been considered as key components of war damages.[1]

In our setup, both the warring states and states that import from them suffer initial war disruptions due to increases in trading costs, with their magnitudes depending upon the first-order (direct) dependence on their respective suppliers. Increases in war-related trade costs feed into prices of imported goods and reduce the real GDP of the importing states, with the effect propagating to all downstream states through network linkages. We show that a matrix of consumption-weighted bilateral network exposures, which is a function of the entire global input-output network and demand structure, measures the direct and indirect impact of initial war disruptions to one state on the real GDP of another. When states that suffer large initial disruptions happen to be those with high direct and indirect effect on a warring state, expected war damages to the warring state would be large.

We adopt a rationalist explanation for war that focuses on information asymmetry as a key factor in driving conflict escalation (Fearon, 1995, for surveys; and Blainey, 1988, for historical illustrations). We assume that peace Pareto dominates war, meaning that peace would always be preferred by both states under complete information. However, this is not the case in an environment with information asymmetry. When an exogenous trigger brings two states to bargain over their total surplus, each state forms expectations on their opponent's wartime utilities (or damages) based on how initial disruptions will propagate across the global production network in the event of war. However, each state also has private information about its own resilience during wartime. Such private information may pertain to a nation's efficiency in managing and defending its wartime economy, or morale and nationalism of its public. In other words, each state has a privately observed *war type*, which informs the state of its own ex post wartime utility. Those ex post wartime utilities, in turn, constitute outside options if peace negotiations fail.

Bargaining proceeds according to Compte and Jehiel's (2004, 2009) incomplete information protocol which we generalize from the original setting of symmetric bargainers to accommodate bargaining between states with varying degrees of asymmetry in their network positions. In this framework, both states simultaneously declare a division of surplus, (or *asking prices for peace*), with conflict ensuing if the sum of these demands exceeds the combined GDP of both states. We show that strategy profiles that would have constituted Bayes Nash equilibria with symmetric (or nearly symmetric) states are no longer optimal. We then characterize a new BNE announcement profile that does not impose any restrictions

[1] For example, during the 1973 Arab-Israel war, Arab members of the OPEC imposed the oil embargo on the United States in retaliation for its military supplies to Israel and for leverage in peace negotiations. Dependence on Russian energy supplies features prominently into Germany's deliberation on support for Ukraine in early stages of the Ukraine-Russian war. To put it simply, input-output linkages can be weaponized in negotiations between states.

on bargainers' relative expected payoffs. In equilibrium, each state has an incentive to ask for more that its outside option. Such over-asking can lead to conflict even if peace Pareto dominates war. Since states internalize the global network structure to form expectations about each other's potential losses when deciding on optimal asking prices for peace, our model introduces a mechanism by which network structure affect the bilateral likelihood of war.

We have three main theoretical findings: First, bilateral probabilities of conflict depend negatively on expected damages and positively on the degree of information asymmetry. We show that each state's optimal asking price for peace decreases with its expected war damages, rendering peace more likely. Moreover, for a given level of expected war outcomes, higher information asymmetry not only presents a potentially more favorable upside but also introduces greater uncertainty about the opponent's outside option. This heightened uncertainty makes escalation through 'bluffing' more likely.

Second, we find that, given a positive probability of war, two states that are highly asymmetric in expected wartime outcomes, due to differences in their network exposure, may have a lower probability of war than two states with symmetric network dependence. This is because asymmetry in expected war outcomes can convey valuable information. In our model, the degree of information asymmetry about the opponent's type is represented by fixed percentage points of deviations from each state's expected wartime utility, defining their best- and worst-case scenarios. Consequently, the state with lower expected wartime utility has a narrower range of outside options, which limits its upside potential in terms of absolute magnitudes. This additional information can help prevent conflict in an environment of incomplete information.

In cases of asymmetry in expected war outcomes, an "off-ramp" to avoid conflict may emerge when the dominant state faces unfavorable outside options, giving it an incentive to seek peace. The logic is as follows: First, we show that, due to the narrower range of outside options available to the dominated state, the dominant state can determine the amount needed to dissuade its opponent from conflict for a wide range of its own outside options. Second, the price tag for the dominated state to forgo its outside option is likely only a small fraction of the dominant state's GDP, making a peace deal both affordable for the dominant state and acceptable to the dominated state, which remains unaware of the dominant state's unfavorable outside option. In contrast, with symmetric or near symmetric states, no such off-ramps exist, as both draw from the same or similar pool of outside options, providing no additional information that could facilitate peace.

Third, we find that when the minimal joint wartime damages are sufficiently large, which can be the result of high expected damages combined with low enough information asymmetry, there will be no escalation to war.

We use a core-periphery production network with a fixed number of states and a symmetric demand composition as an example to illustrate numerically the role of production network architecture in driving conflict probabilities. Here core states symmetrically supply intermediate inputs to all states including themselves, while peripheral states are not intermediate good suppliers. This structure allows us to examine conflict probabilities between symmetric pairs with different degrees of mutual dependence (core-core, periphery-periphery), and asymmetric core-periphery pairs. More importantly, we can quantify changes in the bilateral probability of conflicts between core and peripheral states as we gradually increase the number of cores, and thus altering the degree of asymmetry in their relative network positions. The simulation shows that even in a highly diversified production networks (e.g. 99 core states and only one peripheral), the level of asymmetry in network positions between one of the cores and the pheriphral state can still be too large to be classified as symmetric or nearly symmetric. This highlights the importance of our theoretical contribution in generalizing Compte and Jehiel's (2004, 2009) bargaining theorem to accommodate bargaining states with arbitrary degree of asymmetry in their network positions.

Lastly, we test the theoretical prediction that network architecture affects bilateral probabilities of conflict by combining the Correlates of War (COW) project and the World Input-Output Table (WIOD) during the 1965-2014 period. The COW project describes characteristics of historical dyads of military conflicts and involved states. The WIOD data provide the global production network and demand composition for states that are important in the global economy. We construct a bilateral measure that characterizes asymmetry in two states' mutual network dependence, and use a logit regression model to examine its significance while controlling for various co-determinants of conflicts. Consistent with our theoretical model, we find that a one-standard-error increase in our measure of asymmetry in mutual dependence reduces the odds of broadly defined conflicts by 22 percent. We find that other co-determinants, including contiguity, geographical distance, number of years after conflicts, bilateral openness, and another network measure that compares two states' degree of self-dependence, all yield coefficients that are consistent with our theoretical predictions.

Related Literature: Our paper is closely related to Jackson and Nei (2015), who shows that trade considerations allow the existence of no-war equilibria. However, their network is binary, thus unweighted and undirected. Furthermore, they employ a reduced-form framework, while we provide a micro-founded model that explicitly relates the global production network to probabilities of conflicts.

Martin, Mayer and Thoenig (2008) provide empirical evidence for contrasting effects of bilateral and multilateral trade openness on military conflicts. Our work differs in two key aspects. First, they feature a Dixit-Stiglitz model with no production networks. As a result, states only consider direct, but not second or higher order spillover effects from possible war damages. Second, their bargaining equilibrium only considers the case of two symmetric or nearly symmetric states, thus becomes a special case of our model.

Korovkin and Makarin (2022) provide supportive evidence for taking production networks into account when evaluating damages from the Ukraine war. Kleinman, Liu and Redding (2022) use network measures of economic exposure to foreign productivity growth to empirically detect the impact of China's emergence into the global economy on political realignment of its trade partners. We share their emphasis on the importance of networks, but our focus is on the network effects on military conflicts instead of softer forms of political power. There is a large literature, for example, Caliendo and Parro (2015, 2019), Baqaee and Farhi (2019), Di Giovanni et al. (2014), Clayton et al. (2023) and Antras and Chor (2019), which characterize income and welfare effects of trade shocks in general equilibrium models with a global production network. The conflicts in our model differ from traditional trade wars in two aspects. First, although we do not focus on personnel loss due to conflicts, our model allows for such war damages. Second, traditional trade wars feature two states imposing tariffs or trade barriers on bilateral imports. In our model, two states can engage in conflicts even when they do not engage in bilateral trade. More importantly, our focus is on establishing the linkage through which expected income and welfare effects from war disruptions affect probabilities of conflicts. To that end, the main contribution of our paper, the bargaining equilibrium that relates expected wartime damages to probabilities of conflicts, are compatible with a wide array of trade models.

There has been substantial amount of debate between the liberalist school and the realist view on whether trade promotes peace. Among them are Baribieri (2002), Polachek (1980), Polachek and Mcdonald (1992), Mansfield (1995) and Copeland (1996). Their approaches are primarily empirical and their historical evidence is mixed. In our model, we use the micro-founded measure of bilateral exposures to capture such network dependencies among states. Our network measures are robust predictors of probabilities of conflicts.

The rest of the paper is structured as follows. Section 2 describes our theoretical model that relates an arbitrary global input-output network to bilateral probability of conflicts. Section 3 uses a core-periphery framework to numerically illustrate theoretical predictions of our model. Section 4 provides the empirical evidence. Section 5 concludes.All proofs, equilibrium derivations of the trade model, and robustness checks of our empirical findings are included in the appendix.

2 The Model

There is a set of N states. Two states come to the bargaining table in response to an exogenous trigger. During the bargaining process, each state optimally chooses its asking prices for peace based on publicly and privately observed information. If the offers are compatible, there will be no war, and consequently no disruptions to trade routes. Both states make production decisions based on an Armington-Long-Plosser network model and split their final goods consumption based upon the agreed peace deal. If the negotiation fails, there will be wartime disruptions to bilateral and third-party trading routes, which affect optimal production and consumption decisions of two states. Each states knows its own and the opponent's ex ante expected wartime utilities based on the network model, but does not observe the opponent's war "type", and consequently is uncertain how much the opponent's ex post wartime utilities would deviate from the ex ante expectation. As a result, the two states engage in bargaining with information asymmetry, which may result in war. In the following subsections, we first describe the network model that yields optimal production decision in both peace and wartime.

2.1 An Armington-Long-Plosser Network Model

Among N states, each state i is endowed with a fixed amount of labor $\overline{L}_i$. For simplicity, we assume that labor is not mobile across states. A representative agent in state i derives utility from C_i, a Cobb-Douglas composite of goods produced in all states.

$$U_i = (1 + \tilde{u}_i)C_i = (1 + \tilde{u}_i)\Pi_{j=1}^{N} \left(\frac{c_{ij}}{\beta_{ij}} \right)^{\beta_{ij}}. \tag{1}$$

Here c_{ij} represents consumption of the good produced in state j by state i. The constants β_{ij} measure goods' shares in state i's utility function and satisfy $\sum_{j=1}^{N} \beta_{ij} = 1$. The term $\tilde{u}_i$ represents state i's war type. It equals 0 when state i is not engaged in conflicts. When states i and j are in a conflict, $\tilde{u}_i$ and $\tilde{u}_j$ are drawn from a joint distribution with their respective unconditional expectations equal to 0. The realization of $\tilde{u}_i$ is privately observed before the bargain, and can be used to form expectations of $\tilde{u}_j$ based on their joint distribution. Essentially, we model a state's war type as a multiplicative factor augmenting the final goods consumption. It can be interpreted as a state's wartime (in)efficiency in producing the composite final consumption good, or a states resilience (or lack of) in extracting higher (or lower) utility from the same amount of final goods consumption.

A representative competitive firm in each state produces a differentiated variety under constant returns to scale. The firm uses labor in the home state as well as goods produced in home and foreign states as intermediate inputs for production. The output y_i in state i is given by:

$$y_i = \varsigma_i l_i^{\alpha_i} \Pi_{j=1}^{N} x_{ij}^{g_{ij}}, \tag{2}$$

where l_i is the amount of labor input, x_{ij} is the quantity of good j used for production of good i, and ς_i is a normalization constant.[2] The exponents g_{ij} characterize production network linkages across states. We use $\boldsymbol{G}$ to denote the input-output matrix with entries, $\{g_{ij}\}_{i,j=1,\ldots,N}$, and assume that

$$\alpha_i + \sum_{j=1}^{N} g_{ij} = 1. \tag{3}$$

We introduce iceberg trade costs related to war disruptions to bilateral and third-party trading routes. At time of bilateral conflicts, all affected states, that is, the two warring states that import goods, and all other states that import goods from one of the two warring states, have to pay a surcharge on the goods to cover war-related transportation expenses. Specifically, state i has to pay $\widehat{p}_{ik}$ to import goods from state k,

$$\widehat{p}_{ik} = \frac{p_k}{\widehat{\tau}_{ik}}, \; \widehat{\tau}_{ik} \leq 1; \tag{4}$$

where $\widehat{\tau}_{ik} = 1$ when $i = k$, or when neither i nor k is one of the warring states. Here p_k is the price paid for good k in peacetime. We further define $\tau_{ik} = \log\left(\widehat{\tau}_{ik}\right)$, and $\boldsymbol{\tau}$ the matrix whose ik^{th} element is given by τ_{ik}.

Equilibrium conditions are standard. Due to the multiplicative nature of the term $(1+\tilde{u}_i)$ in the utility function, and the Cobb-Douglas specifications in both the production function and the demand structure, it is straightforward to show that different realizations of $(\tilde{u}_i)$ do not alter either equilibrium quantities or prices. Solving for the equilibrium allocation yields the following vector of logarithm of consumption across states:[3]

$$\log \boldsymbol{C} \;\; = \;\; \left[\boldsymbol{I} - \boldsymbol{\beta}\left(I - \boldsymbol{G}\right)^{-1} \boldsymbol{\alpha}\right] \log \widehat{\mathbf{W}} + \log \overline{\mathbf{L}} + \boldsymbol{\beta}\left(\boldsymbol{I} - \boldsymbol{G}\right)^{-1} \mathbf{T} + \boldsymbol{\Gamma}, \tag{5}$$

where $\boldsymbol{\beta}$ summarizes the final demand composition shares of all states, with entries given by $\{\beta_{ij}\}_{i,j=1}^{N}$, and $\boldsymbol{\alpha}$ represents the diagonal matrix of labor shares. Additionally, $\widehat{\mathbf{W}}$ denotes relative wage ratios defined by $\left[1, \frac{W_2}{W_1}, \cdots, \frac{W_N}{W_1}\right]$, $\overline{\mathbf{L}}$ represents the vector of labor endowments, and $\mathbf{T}$ represents the vector of supply disturbances to each state originating from war-related

[2]Our Armington-Long-Plosser setup can accommodate production technologies and utility functions with the general Dixit-Stiglitz form (i.e., CES functions). We opt for the Cobb-Douglas form as it allows for analytical characterizations of the mechanism that relates the global input-output network architecture to expected war damages.

[3]Equilibrium conditions and details of the derivations are contained in online Appendix D.

iceberg trade costs. Here $\mathbf{T}_j$ is given by $\sum_{q=1}^{N} g_{jq}\tau_{jq}$, the sum of trade costs weighted by state j's first-order dependence on all its suppliers. Similarly, $\mathbf{\Gamma}$ represents the vector of direct disturbances to final consumption goods of each state originating from trade costs. Here Γ_j is given by $\sum_{q=1}^{N} \beta_{jq}\tau_{jq}$, the demand-weighted sum of trade costs incurred by state j.

The relative wage ratios, $\widehat{\mathbf{W}}$, are determined by the goods market equilibrium conditions,

$$\left[\frac{W_1\overline{L}_1}{\alpha_1}, \cdots, \frac{W_N\overline{L}_N}{\alpha_N}\right](\boldsymbol{I} - \boldsymbol{G} - \boldsymbol{\alpha\beta}) = \mathbf{0}. \tag{6}$$

A unique set of positive wage ratios can be obtained in equilibrium under a set of regularity conditions.[4] It can be shown that those conditions allow for situations where two states engage in no bilateral trade. As a result, we can study probability of conflicts between states with no direct trade linkages, which are usually required in the study of conventional trade wars.

We define peacetime utilities as those derived when $\boldsymbol{\tau}$, the logarithm matrix of trading costs, are normalized to 0, there is no loss of labor force to war, and the war type, $(\tilde{u}_i)$, is equal to 0. Equation (5) reduces to

$$\log \mathbf{U}^p = \left[\boldsymbol{I} - \boldsymbol{\beta}\left(\boldsymbol{I} - \boldsymbol{G}\right)^{-1}\boldsymbol{\alpha}\right] \log \widehat{\mathbf{W}} + \log \overline{\mathbf{L}}. \tag{7}$$

Therefore, peacetime utilities (consumption) across states, denoted by $\mathbf{U}^p$, are solely determined by $\boldsymbol{G}$, $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, and the vector of labor endowments.

We denote by U^W the amount of final goods consumption that prevails when there are war-related trading costs $\boldsymbol{\tau}$ and loss of labor $\triangle \log \overline{\mathbf{L}}$. Based on equation (5). It is straightforward to show that log-deviations of U^W relative to the peacetime utilities (consumption) are given by, [5]

$$\log\left(\frac{\mathbf{U}^W}{\mathbf{U}^p}\right) = \boldsymbol{\beta}\left(\boldsymbol{I} - \boldsymbol{G}\right)^{-1}\left(\triangle\mathbf{T} + \boldsymbol{\alpha}\triangle \log \overline{\mathbf{L}}\right) + \triangle\mathbf{\Gamma}. \tag{9}$$

Equation (9) decomposes the logarithm of $\frac{\mathbf{U}^W}{\mathbf{U}^p}$ into two components: the first term summa-

[4] Letting state 1 be the numeraire, and defining $\boldsymbol{Z} = \boldsymbol{G} + \boldsymbol{\alpha\beta}$, regularity requires that (i) $\boldsymbol{I}_{N-1} - \boldsymbol{Z}_{-1}$ is full rank, and (ii) $\boldsymbol{z}_{2,N}^T\left(\boldsymbol{I}_{N-1} - \boldsymbol{Z}_{-1}\right)^{-1}$ is entry wise positive, where $\boldsymbol{Z}_{-1}$ is the matrix obtained by deleting the first row and column of $\boldsymbol{Z}$, $\boldsymbol{z}_{2,N}^T = (z_{12}, ..., z_{1N})$, and $\boldsymbol{I}_{N-1}$ is the $(N-1)\times(N-1)$ identity matrix.

[5] The derivation follows from the observation that $\log \mathbf{C}$ can be written as

$$\begin{aligned}\log \mathbf{C} &= \left[\boldsymbol{I} - \boldsymbol{\beta}\left(\boldsymbol{I} - \boldsymbol{G}\right)^{-1}\boldsymbol{\alpha}\right]\left(\log \widehat{\mathbf{W}} + \log \overline{\mathbf{L}}\right) \\ &\quad + \boldsymbol{\beta}\left(\boldsymbol{I} - \boldsymbol{G}\right)^{-1}\left(\boldsymbol{T} + \boldsymbol{\alpha}\log \overline{\mathbf{L}}\right) + \mathbf{\Gamma},\end{aligned} \tag{8}$$

where $\left(\log \widehat{\mathbf{W}} + \log \overline{\mathbf{L}}\right)$ is the logarithm of nominal income determined in equation (6), as a function of $\boldsymbol{G}, \boldsymbol{\alpha},$ and $\boldsymbol{\beta}$ only.

rizes the direct and indirect impact of war-related shocks through the production network, while the second term reflects changes in the amount of the composite consumption good in direct responses to increases in trade costs. Since we define war as an increase in trading costs and a reduction in labor force, each element of $\boldsymbol{\tau}$ and $\boldsymbol{\alpha}\triangle\log\overline{\mathbf{L}}$ are smaller than or equal to zero, and the right hand side of equation (9) is negative.

Given the multiplicative nature of $(1+\tilde{u}_i)$ and our Cobb-Douglas specifications, different realizations of $\tilde{u}_i$ do not impact relative prices or allocations during war. Consequently, actual wartime utilities, which we denote as $\tilde{U}_i^W$, is given by

$$\tilde{U}_i^W = (1+\tilde{u}_i)U_i^W, \tag{10}$$

Since the unconditional mean of $\tilde{u}_i$ equals 0, U_i^W is effectively the ex ante expected wartime utility prior to the realization of the two states' types. Thus the realized and privately observed value of $\tilde{u}_i$ determines the deviation of the wartime utility from its expectation. This formulation recognizes that economic consequences often anchor expectations of war outcomes. Since both states understand the structure of the network model, state i observes (ex ante) expected wartime utilities, U_i^W and U_j^W, but not $\tilde{U_j^W}$. The opposite is true for state j. In the next subsections we show how the network structure affects expected war damages, and how the information asymmetry regarding actual war damages may lead to war.

2.2 Network, Peacetime Utilities, and Expected War Damages

We analyze how network structures relate to peacetime and expected wartime utilities. It is important for two states at the bargaining table to evaluate their relative standings during peace and war times. In this model, such comparisons can be summarized by three ratios, $\left\{\frac{U_j^P}{U_i^P}, \frac{U_i^W}{U_i^P}, \frac{U_j^W}{U_j^P}\right\}$, with the first ratio capturing relative magnitudes of peacetime utilities, and the latter two expected wartime damages for each state.

In determining the above three ratios, the matrix $\boldsymbol{D} = \boldsymbol{\beta}\left(\boldsymbol{I}-\boldsymbol{G}\right)^{-1}$ plays an important role, whose elements we refer to as consumption-weighted bilateral network exposures. Here $(\boldsymbol{I}-\boldsymbol{G})^{-1}$ is the Leontief inverse that captures how supply shocks, including war-related negative shocks, $\triangle\mathbf{T}+\boldsymbol{\alpha}\triangle\log\overline{\mathbf{L}}$, propagate downstream to other states through the global input-output network. Equation (9) then shows that the term $D_{i,j}$ represents the direct and indirect effects on log consumption of state i from war-related shocks to state j. The higher $D_{i,j}$, the larger the war damages to state i in response to a given magnitude of war-related shocks to state j. These exposure measures matter for assessing the degree of mutual dependence between two states. Thus the consumption-weighted bilateral network exposures matter for both peacetime utilities and expected relative war damages.

2.2.1 The Ratio of Peacetime Utilities

The impact of $\boldsymbol{D}$ on utilities can be best understood in the special case when total labor endowments and labor shares are the same across states, and when demand composition is symmetric across all states. That is, $\boldsymbol{\alpha} = \alpha \boldsymbol{I}$, $\overline{\mathbf{L}} = \mathbf{1}$, and $\beta = \frac{1}{N}\mathbf{U}_{N\times N}$, where $\mathbf{U}_{N\times N}$ represents $N \times N$ matrix of ones. Under this assumption on $\boldsymbol{\beta}$, each row of $\boldsymbol{D}$ is identical and equal to $\frac{1}{N}\boldsymbol{b}^T$, where

$$\boldsymbol{b}^T = \mathbf{1}^T(\boldsymbol{I} - \mathbf{G})^{-1}. \tag{11}$$

Here b_j denotes state $j's$ Katz-Bonacich (KB) centrality, which is the jth column sum of the Leontief inverse. Based on equations (6) and (7), we can show that

$$\frac{U_i^P}{U_j^P} = \frac{b_i}{b_j}, \tag{12}$$

which states that the ratio of peacetime utilities of state i over that of state j is equal to the ratio of their respective KB centrality measures.[6] In this special case, the state that plays a more central role in the global input-output network is the state with larger economic size in terms of utility and consumption. The relation is intuitive from the viewpoint of the balanced trade even in more general cases.

2.2.2 Relative Magnitudes of Expected War Damages

The ratio of ex ante expected wartime utilities, $\frac{U_j^W}{U_i^W}$ depends upon how the ratio of peacetime utilities, $\frac{U_j^P}{U_i^P}$, are altered by the pair of expected war damages $\left\{\frac{U_i^W}{U_i^P}, \frac{U_j^W}{U_j^P}\right\}$. Just as the matrix of consumption-weighted bilateral network exposures determines peacetime utility ratios, it also plays a role in determining expected war damages. When subject to initial supply-side war disruptions, states with higher bilateral network exposures play more important roles in impacting utilities of downstream states.

Initial Supply-Side War Disruption

War-related shocks, $\triangle\mathbf{T} + \boldsymbol{\alpha}\triangle\log\overline{\mathbf{L}}$, serve a role similar to negative supply shocks. Different from idiosyncratic supply shocks featured in Acemoglu et al. (2012) type models, initial war disruptions depend upon which states are at war, as well as their first-order network

[6] Recognizing that $(\boldsymbol{I} - \mathbf{G})^{-1}\boldsymbol{\alpha}\mathbf{1} = \mathbf{1}$, we can show that $\boldsymbol{W} = \boldsymbol{b}$ solves equation (6). Substituting the solution into equation (7) yields equation (12).

connections with each other and all other states. Historically the majority of military conflicts, as defined in COW (Correlates of War Project), do not involve fatalities more than $1,000$. Thus from now on we set $\triangle \log \overline{\mathbf{L}}$ to 0. We make transparent the dependence of $\triangle\mathbf{T}$ on network configurations by parameterizing the matrix of iceberg trading costs $\boldsymbol{\tau}$ induced by war.

Definition 1. Let $\lambda < \mu < 0$. Then, war between states i and j induces the following trading costs:

$$\begin{aligned} \tau_{ij} &= \tau_{ji} = \lambda \\ \tau_{ik} &= \tau_{jk} = \tau_{ki} = \tau_{kj} = \mu, \ \forall k \neq i, j \end{aligned}$$

Here, λ represents war-related bilateral trading costs, and μ third-party trading costs. Essentially we assume that bilateral trading costs between i and j are larger than corresponding trade costs between each warring party and its trade partners. As a result, when states i and j are at war, initial war disruptions, $\triangle\mathbf{T}$, can be written as

$$\triangle\mathbf{T} = (\mathbf{G} \odot \tau)\,\mathbf{1} = \begin{pmatrix} \cdots \\ \lambda g_{ij} + \mu \sum_{k \neq i,j} g_{ik} \\ \cdots \\ \lambda g_{ji} + \mu \sum_{k \neq i,j} g_{jk} \\ \mu\,(g_{ki} + g_{kj}) \\ \cdots \end{pmatrix}. \tag{13}$$

where $(\mathbf{G} \odot \tau)$ is the element wise product of $\mathbf{G}$ and τ. As shown above, for the warring states i and j, initial war disruptions have bilateral and third-party trade components. The first component, $g_{ij}\lambda$, is equal to the change in bilateral trading costs (λ) multiplied by the direct network impact of state j on the downstream state i. If state j has strong first order (direct) impact on state i, conflicts would cause large initial war disruptions to state i. However, if state i does not use state $j's$ good as its intermediate input, initial war disruptions through bilateral trade is zero. The same can be said about the warring state j. The second component represents initial war disruptions to state i as its trading costs with all other states excluding j change by μ. Here $\sum_{k \neq i,j} g_{ik}$ is the inward degree of state i resulting from all other states excluding the two warring states.[7] The more state i directly depends upon those other states, the higher the initial disruptions due to third-party trading costs. Initial negative shocks to any other state k that is not involved in bilateral conflicts between

[7] We subtract g_{ii} from the row sum of the input-output matrix $1 - \alpha_i$ because there are no intra-state iceberg trading costs.

i and j are given by $(g_{ki} + g_{kj})\,\mu$, which depends upon the percentage increase in third-party trading costs and the direct network dependence of state k on warring states i and j.

The composition of $\triangle\mathbf{T}$ shows that both the relative network positions of warring states, and the dependence of downstream states on them matter for initial negative shocks caused by military conflicts. If i and j are two states that are central suppliers to each other and all other downstream states, conflicts between them will cause large initial disruptions even before they propagate downstream. If i and j are asymmetric in terms of their mutual dependence, the state that is less dependent on the other will experience smaller initial supply-side negative shocks.

Covariance Between Network Exposures and Initial War Disruptions

Based on Equation (9), log-deviations of state $i's$ wartime utilities from peacetime utilities is given by,

$$\begin{aligned}\log\left(\frac{U_i^W}{U_i^P}\right) &= \boldsymbol{D}\,(i,:)\,\triangle\mathbf{T} + \mathbf{e}_i'\triangle\boldsymbol{\Gamma} \\ &= \left\{D_{ii}\left[\lambda g_{ij} + \mu\sum_{k\neq i,\,j} g_{ik}\right] + D_{ij}\left[\lambda g_{ji} + \mu\sum_{k\neq i,\,j} g_{jk}\right] + \mu\sum_{k\neq i,\,j} D_{ik}\,(g_{ki} + g_{kj})\right\} \\ &\quad + \mathbf{e}_i'\triangle\boldsymbol{\Gamma}, \qquad (14)\end{aligned}$$

where $\mathbf{e}_i'$ is a row vector whose ith element is 1, and 0 otherwise.

As shown by the three components in the bracket, $\boldsymbol{D}\,(i,:)\,\triangle\mathbf{T}$ captures the direct and indirect effects to state i due to initial war disruptions to states i, j, and the rest of their trading partners. If $\boldsymbol{D}\,(i,:)$ covaries with initial supply-side disruptions, $\triangle\mathbf{T}$, that is, when those states that are key suppliers to state i happen to be states that experience severe initial war disruptions, state i would suffer larger war damages compared to the case where the coincidence is not there. If warring states i and j happen to be the two most exposed suppliers, both to each other and to other states, there will be larger war damages as compared to the case when both states are less important suppliers. However, if a high D_{ii}, which indicates a strong degree of self-dependence, comes with small magnitudes of g_{ij} and $\sum_{k\neq i,\,j} g_{ik}$, relative war damages to state i would be limited due to lack of coincidence between network exposures and initial war disruptions.

The difference in relative expected war damages between states i and j is given by

$$\log\left(\frac{U_i^W}{U_i^P}\right) - \log\left(\frac{U_j^W}{U_j^P}\right) = \left[\boldsymbol{D}\,(i,:) - \boldsymbol{D}\,(j,:)\right](\mathbf{G}\odot\tau)\,\mathbf{1} + \left(\mathbf{e}_i' - \mathbf{e}_j'\right)\triangle\boldsymbol{\Gamma}. \qquad (15)$$

Here, the difference between the rows of i and j reflects how the two warring states are affected by initial war disruptions. Note that even if $\boldsymbol{D}(i,:) - \boldsymbol{D}(j,:) = 0$, and consequently both states share the same percentage damages relative to the peace time, as long as states i and j are asymmetric in their network positions due to differences in $D_{i,j}$ and $D_{j,i}$, we would still observe asymmetry in both peacetime and wartime utilities. In the next section, we show that the ratios $\left\{\frac{U_j^P}{U_i^P}, \frac{U_i^W}{U_i^P}, \frac{U_j^W}{U_j^P}\right\}$ are crucial determinants of war probabilities through a bargaining process.

2.3 Bargaining

We adopt a rationalist explanation for war and focus on the cause of war as a combination of two elements, information asymmetry and incentives to misrepresent. A state, with their expected wartime utilities anchored by the network structure, may still have private information with regard to its war capabilities, in terms of its economic, military or moral strengths. Those war capabilities influence actual war outcomes, which constitute privately observed outside options in negotiations. During the bargaining process, each state optimally chooses its asking price (for peace) based on privately observed information, while taking expectation over the opponent's outside option. We show that bluffing may improve bargaining outcomes, but at the risk of a higher probability of war. When the asking prices of two state exceed the total surplus on the table, war occurs.

We follow the incomplete information bargaining protocol of Compte and Jehiel (2004, 2009). Martin, Mayer and Thoenig (2008) also adopt the protocol, but their theoretical model only deals with the case of two symmetric or nearly symmetric states. However, asymmetry in position is a key feature in most network architectures. To address the challenge, we generalize the bargaining framework and derive optimal bargaining strategies for arbitrary pair of states, either symmetric or asymmetric. Martin, Mayer and Thoenig (2008) thus become a special case in our framework.

2.3.1 The Bargaining Environment

Consider two unitary states, i and j, which, in response to an exogenous trigger, enter into negotiations regarding the division of their total utility, $S^P \equiv U_i^P + U_j^P$. Each U_k^P, $k = i,\ j$, represents state $k's$ peacetime utility determined in (7). In the event that negotiations fail, i.e. a division of the surplus is not agreed upon, war is triggered. In this case, each state receives its wartime utility, $\tilde{U}_k^W = (1 + \tilde{u}_k)U_k^W$, as derived in equation (10). Here $\tilde{U}_k^W$ is the equilibrium outcome resulting from state k's optimal consumption and production decisions, which can be considered as each state's outside option.

The term $(1+\tilde{u}_k)$ characterizes how state k fares in its wartime economy despite disruptions to bilateral and third-party trading routes. We further assume that $\tilde{u}_i$, $\tilde{u}_j$ are jointly and uniformly distributed in an isosceles right triangle with $-\frac{V}{2} \leq \tilde{u}_k \leq V$, where $V > 0$.[8] The distributional assumptions on $\tilde{u}_k$ imply that $\tilde{U}_k^W \in [v_k,\, \bar{v}_k]$ where $v_k = (1-\frac{V}{2})U_k^W$ and $\bar{v}_k = (1+V)U_k^W$, $k = i,\, j$. Given the distribution, it is straightforward to show that $E\tilde{u}_k = 0$ and U_k^W, as determined in equation (9), is the ex ante expected wartime utility. Privately observed $\tilde{u}_i$ and $\tilde{u}_j$ are partially correlated, which is reasonable in the context of warfare. A higher V means a larger variance of the opponent state's outside option, and hence higher information asymmetry. The distribution of wartime utilities are common knowledge to both states.

Given the above, wartime utilities of the two bargaining states are uniformly distributed in the following region $\mathcal{O}$, which is a right triangle with the right angle vertex at (v_i, v_j)

$$\mathcal{O} = \left\{ (\tilde{U}_i^W,\, \tilde{U}_j^W) |\, \tilde{U}_k^W \geq v_k,\, k = i,\, j \,\text{and}\, \tilde{U}_j^W \leq \eta_j \left(\tilde{U}_i^W \right) \right\},$$

where,[9]

$$\eta_j \left(\tilde{U}_i^W \right) = v_j + \bar{v}_j - \frac{U_j^W}{U_i^W} \tilde{U}_i^W,$$

is the maximal outside option state j can have conditional on $i's$ realization $\tilde{U}_i^W$. Lastly, we assume that peace Pareto dominates war:

$$S^P \equiv U_i^P + U_j^p > \tilde{U}_i^W + \tilde{U}_j^W \equiv \tilde{S}^W$$

Figure 1 provides a graphic illustration of $\mathcal{O}$ as the bold triangle enclosed by the sum of peacetime utilities S^P. The coordinate (U_i^W, U_j^W) represents expected wartime utilities. Conditional on drawing the outside option Y, state j knows that state $i's$ outside option is uniformly distributed along the solid horizontal line within the triangle whose vertical coordinate is Y.

[8] The uniform distribution assumption is important for deriving analytical expressions for probability of conflicts, and for proving that the Nash Bargaining protocol we adopt in the model is second best. However, as shown in Compte and Jehiel (2004, 2009), the imposition of a uniform distribution is not a necessary condition for inefficiencies (in our context, conflicts) to arise.

[9] Note that the second condition in $\mathcal{O}$ can be rewritten as $\tilde{U}_i^W \leq \eta_i \left(\tilde{U}_j^W \right)$ where $\eta_i \left(\tilde{U}_j^W \right) = v_i + \bar{v}_i - \frac{U_i^W}{U_j^W} \tilde{U}_j^W$ is the maximal outside option state i can have conditional on $j's$ realization $\tilde{U}_j^W$.

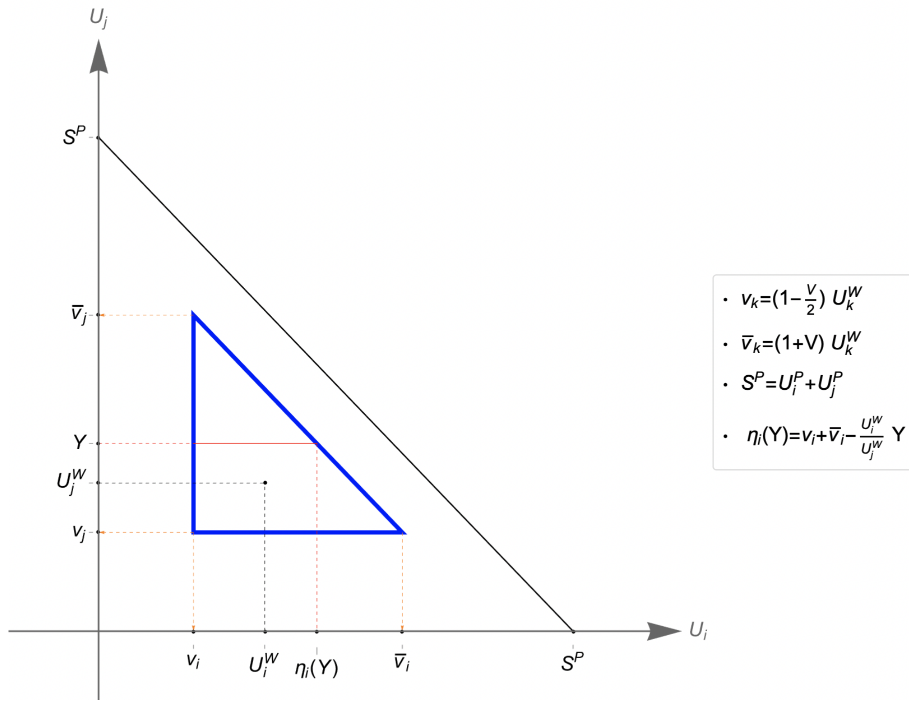


Figure 1: Distribution of outside options. The horizontal and vertical axes represent respectively utilities of states i and j.

2.3.2 The Bargaining Protocol

We adopt a Nash Bargaining protocol that maximizes the ex ante total gain of two states from bargaining. Although an institutional restriction, the adoption of such a protocol prior to the realization of private outside options is reasonable and consistent with the rationalist view of states' optimization.[10] The bargaining protocol consists of two stages: (i) the announcement stage, and (ii) the agreement stage. In the announcement stage, states simultaneously declare their asking prices for peace, $(\hat{U}_i^W,\, \hat{U}_j^W)$. If announcements are not compatible with total surplus, i.e. $\hat{U}_i^W + \hat{U}_j^W > S^P$, the game ends and war is triggered. In this case, states receive their true outside options $(\tilde{U}_i^W,\, \tilde{U}_j^W)$. However, if announcements are compatible with total surplus i.e. $\hat{U}_i^W + \hat{U}_j^W \leq S^P$, then each state is set to receive its announced asking price for peace in addition to half the remaining surplus. This is given by:

$$\tau_k(\hat{U}_i^W,\, \hat{U}_j^W) = \hat{U}_k^W + \frac{S^P - (\hat{U}_i^W + \hat{U}_j^W)}{2},\ k = i,\, j \tag{16}$$

If announcements are compatible the agreement stage is reached. In this case, states sequentially declare if they accept or do not accept (16). It is optimal for state k to accept

[10] The proof that the Nash Bargaining protocol maximizes expected total gains and delivers second best outcome is contained in online Appendix C.

the peace deal if it gets more than its outside option. If both accept, then they receive $\tau_k(\hat{U}_i^W, \hat{U}_j^W)$. If either of them rejects, war is triggered, and each state receives its true outside option.[11]

2.3.3 Optimal Bargaining Strategies

Definition 2. A Bayesian-Nash equilibrium (BNE) is a tuple $(\hat{U}_i^{W*}, \hat{U}_j^{W*})$ consisting of a mutual best response profile where each state is maximizing its expected payoff, conditional on its private observation of $\tilde{U}_i^W$ or $\tilde{U}_j^W$. Specifically,

$$\hat{U}_i^{W*} = arg\,\underset{\hat{U}_i^W}{max} \int_{v_j}^{\eta_j(\tilde{U}_i^W)} \Phi_i(\hat{U}_i^W, \hat{U}_j^{W*}; \tilde{U}_i^W) df(\tilde{U}_j^W|\tilde{U}_i^W), \tag{17}$$

where $f(\tilde{U}_j^W|\tilde{U}_i^W)$ is the cumulative distribution function of $\tilde{U}_j^W$ conditional on state $i's$ private observation of $\tilde{U}_i^W$, with its support between v_j and $\eta_j\left(\tilde{U}_i^W\right)$. The payoff function is given by

$$\Phi_i(\hat{U}_i^W, \hat{U}_j^{W*}; \tilde{U}_i^W) = \begin{cases} \tau_i(\hat{U}_i^W, \hat{U}_j^{W*}) & \hat{U}_i^W + \hat{U}_j^{W*} \leq S^P \\ & \& \ \tau_i(\hat{U}_i^W, \hat{U}_j^{W*}) \geq \tilde{U}_i^W \\ \tilde{U}_i^W & else \end{cases} \tag{18}$$

The corresponding definition holds for state j.

We extend Compte and Jehiel (2004, 2009) to characterize the optimal decision rules of states i and j, allowing for any possible levels of asymmetry between two states in terms of peacetime and wartime utilities, a departure from Martin, Mayer and Thoenig (2008). Without loss of generality, we designate state i as the dominant state with higher or equal expected wartime utilities, that is, $U_i^W \geq U_j^W$.

Theorem 1. *Denote $R = \frac{3}{4}S^P + \frac{1}{4}(v_i + v_j)$, $\overline{V}_i = \overline{v}_i + v_j$ and $\overline{V}_j = \overline{v}_j + v_i$. There exists a Bayesian-Nash equilibrium that supports the following outcome: Conditional on states i and j entering the bargaining process, there is war between the two states if $(\tilde{U}_i^W, \tilde{U}_j^W) \in \mathcal{D}$, and*

[11] The agreement stage allows the two states to veto any deal reached in the announcement stage prior to its implementation. Compte and Jehiel (2004, 2009) show that such ex post veto power is essential for their impossibility theorem when the distribution of outside options are correlated. Specifically, Myerson and Satterthwaite (1983) show the general impossibility of ex post efficient mechanisms without outside subsidies, under the assumptions that privately observed valuations are independently distributed between the buyer and the seller, and the distributions are such that there is uncertainty as to which agent values it more. Compte and Jehiel (2004, 2009) relax the assumption on independent distributions, and show that the ex post veto power restriction is essential to reestablish the general impossibility of implementing ex post efficiency in the generalized setting. As a result, the impossibility theorem of Compte and Jehiel's (2004, 2009) applies in our setting, which allows conflicts to arise.

no war otherwise, where

$$\mathcal{D} = \left\{ (\tilde{U}_i^W,\, \tilde{U}_j^W) |\, R < \tilde{U}_i^W + \tilde{U}_j^W \leq S^p \right\}.$$

Moreover, let

$$a(\tilde{U}_k^W) = v_k + \frac{1}{4}(S^P - v_i - v_j) + \frac{2}{3}(\tilde{U}_k^W - v_k), \tag{19}$$

then the Bayesian Nash Equilibrium that supports the above war outcome is given by[12]

$$(\hat{U}_i^{W*},\, \hat{U}_j^{W*}) = \begin{cases} \left(a(\tilde{U}_i^W), a(\tilde{U}_j^W)\right) & if\;\; R \leq \min\left(\overline{V}_i, \overline{V}_j\right) \quad \textit{Case I} \\ \left(h(\tilde{U}_i^W), a(\tilde{U}_j^W)\right) & if\;\; \overline{V}_j \leq R < \overline{V}_i \quad \textit{Case II} \\ \left(h(\tilde{U}_i^W), a(\tilde{U}_j^W)\right) & if\;\; R \geq \max\left(\overline{V}_i, \overline{V}_j\right) \quad \textit{Case III} \end{cases}, \tag{20}$$

where

$$h(\tilde{U}_i^W) \;=\; a\left(\tilde{U}_i^W + \max\left(Q + \left(\frac{U_j^W}{U_i^W} - 1\right)\left(\tilde{U}_i^W - v_i\right), 0\right)\right), \tag{21}$$

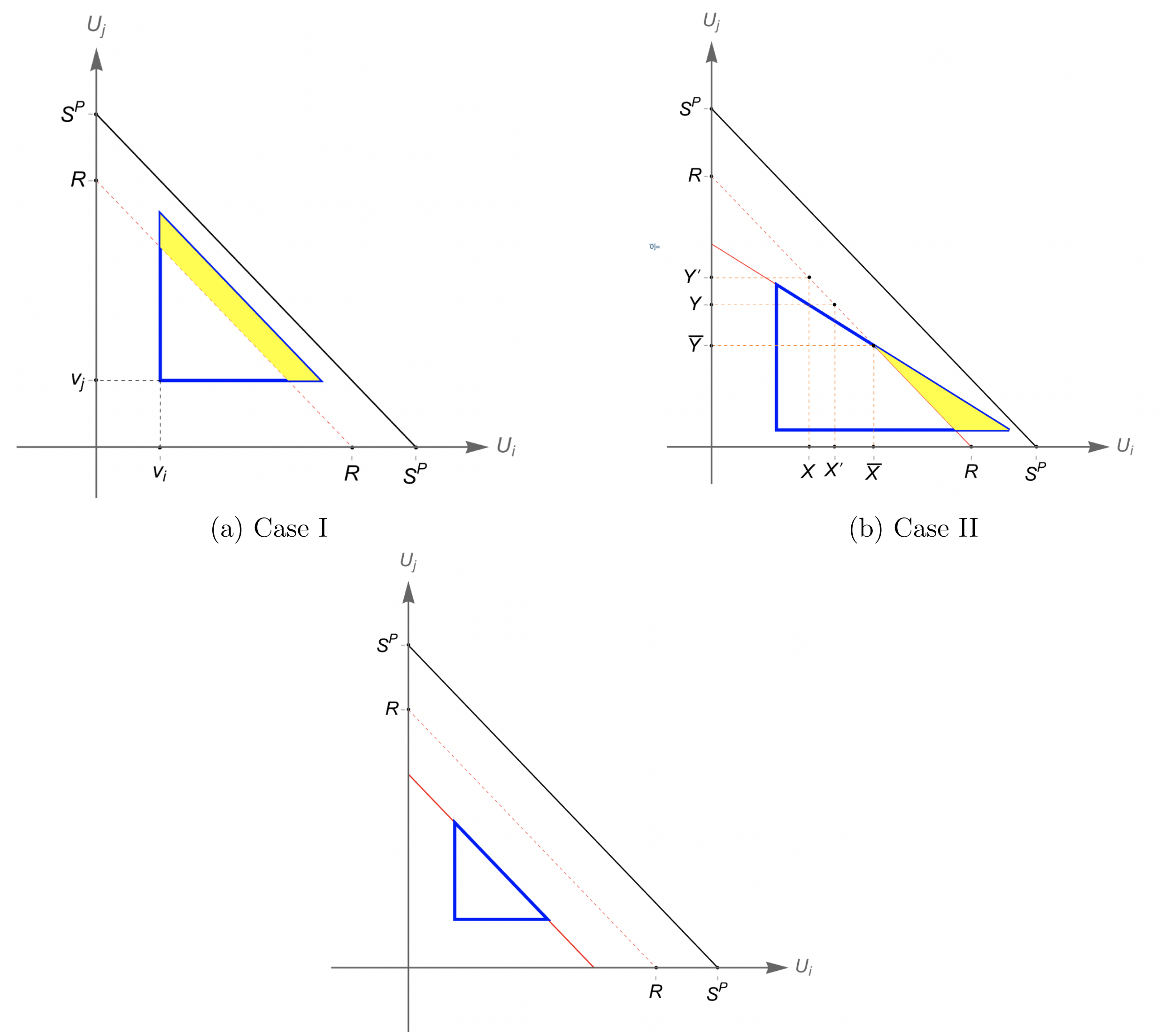
$$Q \;=\; \frac{3}{4}(S^P - v_i - v_j) - \frac{3}{2} V U_j^W. \tag{22}$$

Here $\overline{V}_k$ denotes the sum of the two states' outside options when state k draws the highest possible outside option value, while its opponent the lowest. The pair $\overline{V}_i$ and $\overline{V}_j$ identify the position of each state's outside vertex in the support $\mathcal{O}$.

It is straightforward to show that the inequality $a(\tilde{U}_i^W) + a(\tilde{U}_j^W) \leq S^p$ reduces to $\tilde{U}_i^W + \tilde{U}_j^W \leq R$. Therefore, R denotes the threshold at which the sum of the two states' outside options are exactly compatible to avoid conflicts when both states are optimally choosing the bargaining strategy $a(\tilde{U}_k^W)$.

Figure 2 provides a graphic illustration of Theorem 1. Panel (a) depicts Case I, when both vertices of the support $\mathcal{O}$, which represent best case scenarios of states i or j, are beyond the threshold line characterized by $\tilde{U}_i^W + \tilde{U}_j^W = R$. For the condition to be satisfied, states i and j need to be either symmetric or mildly asymmetric, that is, when $\frac{U_j^W}{U_i^W}$ equal 1 or is slightly less than 1. This occurs when states i and j have similar expected war utilities, which reflect their approximately symmetric network positions. Theorem 1 shows that in Case I, both states will optimally choose the bargaining strategy $a(\tilde{U}_k^W)$. This decision rule

[12] The Nash equilibrium is not unique as $\left(a(\tilde{U}_i^W), h(\tilde{U}_j^W)\right)$ also constitute Nash Equilibrium in Cases II and III. However, despite the multiplicity of Nash Equilibrium, it is straightforward to show that the threshold for war remains the same in Cases II and III. Consequently the probability of war is the same for all Nash equilibrium strategies.



(a) Case I

(b) Case II

(c) Case III

Figure 2: Theorem 1

dictates that both states' optimal announcements are strictly increasing in their privately observed outside options. When both states draw high enough options, bluffing would lead to incompatible asking prices for peace, and result in war. In Panel (a), war occurs in the shaded quadrilateral region, a fraction of the entire support of outside options. Case I encompasses the Bayesian-Nash equilibria of both Compte and Jehiel (2004, 2009) and Martin et al. (2008) as a special cases of our theorem.

Panel (b) depicts Case II when $\frac{U_j^W}{U_i^W}$ is sufficiently small and U_i^W sufficiently large so that the vertex that represents the best case scenario for state i lies outside the threshold, but that for state j lies inside the threshold. This may occur when states i and j hold highly asymmetric network positions, in particular, when state j relies more on state i for intermediate supplies than the other way around. We find that the BNE defined by the pair of optimal decision rules $a(\tilde{U}_k^W)$ is no longer an equilibrium. Conditional on observing an outside option at X, state i is aware that the highest outside option state j can achieve is Y. It thus infers that if both states follow $a(\tilde{U}_k^W)$, there will be unclaimed surplus left on the table, as $a(X) + a(Y) < R$. As a result, state i can ask for more than $a(X)$ without triggering a war. Indeed we show that when state i has an outside option below $\overline{X}$, the tuple $\left(h(\tilde{U}_i^W), a(\tilde{U}_j^W)\right)$ constitutes a Baynesian Nash Equilibrium. We show in Appendix A that $h(\tilde{U}_i^W) + a\left(\eta_j\left(\tilde{U}_i^W\right)\right) = S^P$, that is, the optimal decision of state i when $\tilde{U}_i^W < \overline{X}$ is to extract the maximum on the bargaining table without risking war. Since $\eta_j\left(\tilde{U}_i^W\right)$ is the highest $\tilde{U}_j^W$ possible for any realization of $\tilde{U}_i^W$, the threshold of war for this range of $i's$ outside options becomes $h(\tilde{U}_i^W) + a(\tilde{U}_j^W) = S^p$, coinciding with the hypotenuse of the triangle support. As a result, the threshold for war becomes a line kinked at $\tilde{U}_i^W = \overline{X}$.

In case II, war occurs in the shaded obtuse triangle out of the entire triangle support. When state j draws a realization below $\overline{Y}$, it is faced with a high conditional variance of state $i's$ possible outside options. We show that state j optimally chooses to bluff. If state i has an exceptionally high realization, which is of relatively small probability, war occurs.

The key takeaway from panel (b) is that in an environment of incomplete information and partially correlated private signals, asymmetry can be revealing. The upper triangle defined by $\tilde{U}_i^W \leq \overline{X}$ and $\tilde{U}_j^W \geq \overline{Y}$ constitutes the off-ramp region where asymmetry in expected war utilities reveals enough information for both states to know for certain that if they follow optimal decision rules $\left(h(\tilde{U}_i^W), a(\tilde{U}_j^W)\right)$, war does not occur. Here the dominant state draws a relatively low outside option and has incentives to avoid the war. Due to the asymmetric expected war utilities and consequently asymmetric supports of outside options, the price tag for the dominated state to forego its outside option is likely only a small percentage of the dominant state's GDP. In the off-ramp region, a peace deal is both affordable for the dominant state and acceptable to the dominated state unaware of its opponent's unfavorable situation. This is in sharp contrast to Case I where such an off ramp does not exist, and any asking prices following the optimal strategies can lead to war. Since information asymmetry is the key reason for war, asymmetry in expected war utilities reveals information and reduces odds of war.

Lastly, panel (c) depicts Case III, when the entire support $\mathcal{O}$ lies within the threshold. This happens when sufficiently large expected war damages combine with sufficiently low degree of information asymmetry. Similar to Case II, both states have an incentive to deviate from $\left(a(\tilde{U}_i^W), a(\tilde{U}_j^W)\right)$. We show that $\left(h(\tilde{U}_i^W), a(\tilde{U}_j^W)\right)$ still constitutes a BNE. In both symmetric and asymmetric cases, the new threshold line shifts inwards and coincides with the hypotenuse of the triangle support. Therefore, the probability of war is zero.

It is straightforward to show that $h_k(\tilde{U}_k^W) \geq a(\tilde{U}_k^W) \geq \tilde{U}_k^W$ as long as announcements are compatible. As a result, both states would agree to the split of the surplus in the agreement stage. The theorem shows that both states may have incentives to overstate their outside options in the given environment of information asymmetry, and such misrepresentations lead to war. Below we derive expressions of war probabilities in all the three cases.

2.4 Probabilities of War

The theorem below provides a complete characterization of the escalation probability that allows for asymmetric wartime and peacetime utilities and any admissible degree of information asymmetry V.

Theorem 2. *Designate state i as the dominant state with higher or equal expected wartime utilities, that is, $U_i^W \geq U_j^W$. Denote $V^{\max} = \min\left\{2, \frac{S^P - S^W}{U_i^W - \frac{1}{2}U_j^W}\right\}$, where $S^W = U_i^W + U_j^W$. If $V \leq V^{\max}$, conditional on two states i and j entering the bargaining protocol, the probability of escalation into conflict between the two states is characterized by*

$$pr_{ij} = \begin{cases} 1 - \frac{1}{4V^2}\frac{\left[S^P - (v_i + v_j)\right]^2}{U_i^W U_j^W} & if \;\; R \leq \min\left(\overline{V}_i, \overline{V}_j\right) \quad Case\ I \\ \frac{\left\{\frac{3}{2}VU_i^W - \frac{3}{4}\left[S^P - (v_i + v_j)\right]\right\}^2}{\left(\frac{3}{2}VU_i^W\right)^2}\frac{U_i^W}{U_i^W - U_j^W} & if \;\; \overline{V}_j \leq R < \overline{V}_i \quad Case\ II \\ 0 & if \;\; R \geq \max\left(\overline{V}_i, \overline{V}_j\right) \quad Case\ III \end{cases}. \tag{23}$$

The value of V cannot exceed $\frac{S^P - S^W}{U_i^W - \frac{1}{2}U_j^W}$, at which the maximum sum of outside options, $\overline{V}_i$, exactly equals S^p. It also cannot exceed 2 as the lowest possible outside option, $v_k = \left(1 - \frac{V}{2}\right)U_k^W$, cannot be negative.

As shown in Panels (a) of Figure 2, the probability of war is given by one minus the ratio of the area of the unshaded region over the triangle area that represents the entire support of outside options. In Panel (b), the probability of war is equal to the ratio of the shaded obtuse triangle over the entire support of the outside options. Probabilities of war are zero in Panel (c).

Based on Theorem 2, we show in the following subsections that probabilities of war, including the inequality conditions that define all cases, depend upon three factors: $\left\{\frac{S^P}{U_i^W}, \frac{U_j^W}{U_i^W}; V\right\}$, where $\frac{S^P}{U_i^W}$ represents expected war damages to the dominant state i relative to the sum of the two states' peacetime utilities, and $\frac{U_j^W}{U_i^W}$ captures the asymmetry in the two states' network positions in terms of their expected wartime utilities. We can easily show that $\left\{\frac{S^P}{U_i^W}, \frac{U_j^W}{U_i^W}\right\}$

are respectively functions of the two states' expected war damages $\left\{\frac{U_i^W}{U_i^P}, \frac{U_j^W}{U_j^P}\right\}$ and the ratio of their peacetime utilities, $\frac{U_i^P}{U_j^P}$. All the ratios can be derived from the underlying production network using equations (7) and (9). Thus Theorem 2 establishes the linkage between the global input-ouput production network and bilateral probabilities of war between any arbitrary pair of states.

Before we proceed to discuss various properties of the probability of conflicts, it is important to note that while the bargaining equilibrium is partially driven by expected war damages generated by our trade model, the incentive structure governing equilibrium announcements (and consequently the probabilities of escalation) hold despite of the specifics of any trade framework. For instance, one may adopt a CES production function instead of a Cobb-Douglas form in our model. While an elasticity different from 1 may either facilitate or restrict substitution from trade partners, such considerations would only alter relative expected damages to the two bargaining states. Both our theorem and subsequent lemmas would still go through.

2.4.1 Bilateral Symmetry

First, consider the case in which the two states are assumed to have symmetric fundamentals $\frac{U_i^P}{U_j^P} = 1$ and $\frac{U_i^W}{U_i^P} = \frac{U_j^W}{U_j^P} = \frac{U^W}{U^P}$. The probability of conflicts in Case I reduces to

$$pr_s = 1 - \left[\frac{1}{2} + \frac{1}{V}\left(\frac{1}{2}\frac{S^p}{U^W} - 1\right)\right]^2. \tag{24}$$

We have the following lemma:

Lemma 1. *In the case of bilateral symmetry, the probability of war between two symmetric states depends upon* $\left\{\frac{S^p}{U^W}, V\right\}$.
(1) For any given V, pr_s *is decreasing in expected war damages,* $\frac{S^p}{U^W}$. *It is strictly decreasing when* pr_s *is positive.*
(2) For any given $\frac{S^P}{U^W}$, *the probability of war between two symmetric states is zero in Case III, that is, when* $V \leq \min\left(2, \frac{S^P}{U^W} - 2\right)$; *and the probability of war is increasing in* V *for* $V \in \left[\min\left(2, \frac{S^P}{U^W} - 2\right), V^{\max}\right]$. *The maximum probability of war,* $\frac{7}{16}$ *(or 43.75%), is obtained when* $V = V^{\max} = 2\frac{S^P}{U^W} - 4 \leq 2$.

There are two margins that drive the probability of escalation into conflict. The first is the expected war damages to each state. For any given V, pr_s is strictly decreasing in those damages. The reason is that equilibrium announcements are strictly decreasing in expected war damages.[13] Lower announcements increase the likelihood of a compatible division of the surplus during the bargaining stage.

The second margin that drives the escalation probability is the degree of information asymmetry V. Since each state decides on its optimal asking price for peace based on the expected war outcome of its opponent, higher information asymmetry implies a larger likelihood that the opponent will draw a higher than expected outside option. In turn, this leads to a higher probability of incompatible announcements and a higher likelihood of war.

While it is theoretically possible to isolate the impact of expected damages from that of information asymmetry by holding the latter fixed, the amount of expected war damages affects the maximum value V can take. Specifically, the upper bound of information asymmetry, $V^{\max}$, is equal to $\min\left(2, 2\frac{S^P}{U^W} - 4\right)$. Since pr_s depends positively on V, when expected damages are sufficiently large such that $2 < 2\frac{S^P}{U^W} - 4$, the maximum probability of conflict between two symmetric states will be smaller than $\frac{7}{16}$. When expected damages are sufficiently small such that $2\frac{S^P}{U^W} - 4 \leq 2$, the maximum probability of conflict of $\frac{7}{16}$ can be attained.

Given the opposite impacts of expected war damages and information asymmetry on the probability of conflicts, the larger the expected damages from a bilateral conflict, the higher the degree of information asymmetry is required for any conflicts to occur.

For symmetric states, expected war damages are smallest when both states expect to suffer none or the least amount of direct and indirect damages from initial war disruptions. In this case, not only conflicts can be triggered by a small amount of information asymmetry, but a small increase in information asymmetry can also dramatically raise the odds of conflicts, even to their maximum level.

2.4.2 Bilateral Asymmetry

Without loss of generality, we examine the probability of war when $U_i^W > U_j^W$. Simple algebraic manipulations yield alternative expressions of the probabilities of war in Case I, that is, $R \leq \min\left(\overline{V}_i, \overline{V}_j\right)$, as well as Case II, $\overline{V}_j \leq R < \overline{V}$.

$$pr_{ij} = \begin{cases} 1 - \frac{1}{4V^2}\left[\frac{S^P}{U_i^W} - \left(1 - \frac{V}{2}\right)\left(1 + \frac{U_j^W}{U_i^W}\right)\right]^2 \frac{1}{U_j^W/U_i^W} & if\ R \leq \min\left(\overline{V}_i, \overline{V}_j\right) \\ \left\{1 - \frac{1}{2V}\left[\frac{S^P}{U_i^W} - \left(1 - \frac{V}{2}\right)\left(1 + \frac{U_j^W}{U_i^W}\right)\right]\right\}^2 \frac{1}{1 - U_j^W/U_i^W} & if\ \overline{V}_j \leq R < \overline{V}_i \end{cases} \quad (25)$$

We have the following lemma:

[13]In the case of symmetry we have that $U_i^W = U_j^W$. Letting $U_i^W = U^W$, simple calculation shows that $\frac{\partial a(\tilde{U}_k^W)}{\partial U^W} > 0$ for $k = i, j$

Lemma 2. *In the case of bilateral asymmetry where* $U_i^W > U_j^W$*,*

(1) Everything else fixed, the probability of war between states i and j depends negatively upon $\frac{S^P}{U_i^W}$ *and positively upon* $\frac{U_j^W}{U_i^W}$ *in Cases I and II.*

(2) For any given $\left\{\frac{S^P}{U_i^W}, \frac{U_j^W}{U_i^W}\right\}$*, the probability of war between states i and j is zero in Case III, that is, when* $V \leq \min\left(\frac{2(S^P - S^W)}{3U_i^W - U_j^W}, 2\right)$*; and the probability of war is increasing in V in Cases I and II, that is, when* $V \in \left[\min\left(\frac{2(S^P - S^W)}{3U_i^W - U_j^W}, 2\right), V^{\max}\right]$*. In Case II,* $(\overline{V}_j \leq R < \overline{V}_i)$*, the maximum probability of war,* $pr_{ij} = \frac{1}{4}$*, is obtained when* $V = V^{\max} = \frac{2(S^P - S^W)}{2U_i^W - U_j^W} \leq 2$ *and* $\frac{U_i^W}{U_i^W - U_j^W} = 4$*.*

(3) In Case I, $R \leq \min(\overline{V}_i, \overline{V}_j)$*, the probability of war approaches that in the symmetric case as* $\frac{U_j^W}{U_i^W}$ *approaches* 1*.*

Consistent with the case of bilateral symmetry, the larger the expected war damages, the smaller the probability of war for given levels of V and $\frac{U_j^W}{U_i^W}$. Also consistent with the case of bilateral symmetry, a higher V leads to a higher probability of war. In a departure from the symmetry case, for fixed levels of V and expected damages, the probability of war is increasing in $\frac{U_j^W}{U_i^W}$. That is, the more asymmetric expected war utilities are, the smaller the probability becomes.

Similar to the symmetry case, the amount of expected damages affects the lowest threshold of V for conflicts to occur, as well as its upper bound. The lowest threshold is given by, $\frac{2\left(\frac{S^P}{S^W} - 1\right)}{\left(3U_i^W - U_j^W\right)/S^W}$, which reduces to $\frac{S^P}{U^W} - 2$ in the case of symmetry. Since the denominator decreases from 3 in the case of extreme asymmetry ($\frac{U_j^W}{U_i^W}$ approaches 0) to 1 in the case of symmetry ($\frac{U_j^W}{U_i^W} = 1$), more asymmetric expected damages to the two states mean a lower threshold for conflicts to occur when we hold $\frac{S^P}{S^W}$ fixed. This makes intuitive sense as $\frac{S^P}{U_i^W}$ has to decline with $\frac{U_j^W}{U_i^W}$ to keep $\frac{S^P}{S^W}$ fixed. A lower $\frac{S^P}{U_i^W}$ means that the dominant state has less to lose in case of war, and thus is more likely triggered into conflicts. However, the possible upper bound, $\frac{2\left(\frac{S^P}{S^W} - 1\right)}{\left(2U_i^W - U_j^W\right)/S^W}$, also decreases as expected damages become more asymmetric. This says that although two asymmetric states may enter into conflicts while having lower information asymmetry between them compared to symmetric pairs, the maximum probability they do so is capped to a lower level due to the tighter upper limit on the degree of information asymmetry. Given the Pareto dominance of peacetime utilities, this also makes intuitive sense as a dominant state that suffers small expected damages may expect limited upside from war outcomes.

For pairs with comparable $\frac{S^P}{S^W}$, we may observe mostly conflicts between pairs of asymmetric states when V is in a relatively low region. This region of V is high enough for conflicts to occur when two states are highly asymmetric, but too low for conflicts to occur between symmetric states, even at comparable war damages. Once V is in the region where symmetric conflicts have a positive probability of happening, conflicts between symmetric pairs become more likely.

As discussed in the bargaining section, asymmetry in network position reveals information and enhances the chance of peaceful resolutions. That is the reason why probability of conflicts between symmetric pairs of states would be higher than asymmetric pairs when V is in a reasonably high region, even when we hold V fixed across the two pairs.

3 Probabilities of War in a Core-Periphery Network

In this section we study probabilities of conflicts when the input-output network belongs to a special class of networks known as *core-periphery* networks. An input-output network has a core-periphery architecture if it consists of n_c *core* vertices that supply intermediate goods to all others and purchase only from other core vertices, and $n_p = N - n_c$ *peripheral* vertices that only purchase intermediate goods from the core. The star ($n_c = 1$), the empty ($n_c = 0$), and the complete network ($n_c = N$) are special cases of core-periphery networks. In order to focus on the role of network structures, we impose the following three assumptions throughout this section: $\boldsymbol{\beta} = \frac{1}{N}\mathbf{U}_{N\times N}$, $\overline{\mathbf{L}} = \mathbf{1}$, and $\boldsymbol{\alpha} = \alpha\mathbf{I}$. The adjacency matrix of our core periphery network thus assumes the form:

$$\mathbf{G} = (1-\alpha)\left(\frac{1}{n_c}\mathbf{U}_{N\times n_c}, \mathbf{0}_{N\times(N-n_c)}\right)$$

where $\mathbf{U}_{N\times n_c}$ is a $N \times n_c$ matrix of 1's and $\mathbf{0}_{N\times(N-n_c)}$ is a $N\times(N-n_c)$ matrix of 0's.

Given our assumptions, all core states are identical and all peripheral states are also identical. We have a hierarchical structure of KB centralities of cores and peripheries, $\{b_c, b_p\}$ given by:

$$b_c = \left(1 + \frac{N}{n_c}\frac{1-\alpha}{\alpha}\right), b_p = 1. \tag{26}$$

Such a hierarchical structure allows us to examine the role of networks in two separate aspects. First, we can characterize the role of symmetry and asymmetry, as well as the role of the magnitude of KB centralities in driving war probabilities by studying conflicts between two core states, two peripheral states, and between a core and a peripheral state. Second, by varying the ratio $\frac{N}{n_c}$, we can examine how a gradual change from a uni-core to multi-core global trade framework affects pair-specific war probabilities. Figure 3 illustrates a core-periphery framework with two core and two peripheral states.

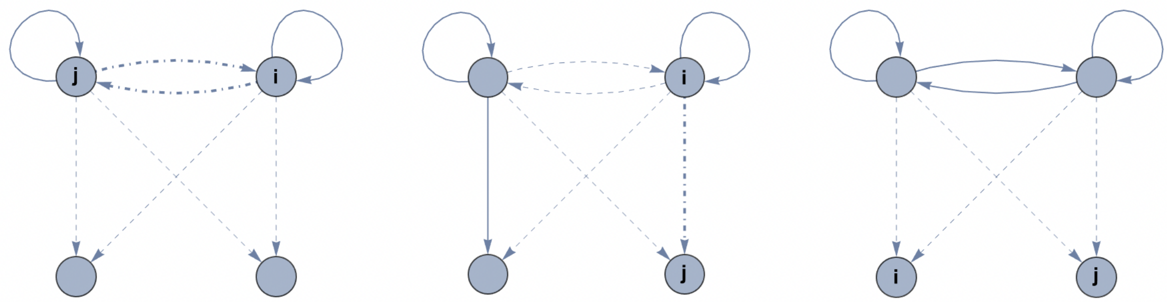


Figure 3: Core-Periphery Network with two core and two peripheral states. Countries i and j designate the pair escalating tensions. Dot-dashed links represent war-related bilateral costs (λ) while dashed links third party costs (μ). Solid links are not affected during conflict.

For numerical calculations, we set N to 100, α to $\frac{2}{3}$, λ to $\log(0.7)$, and μ to $\log(0.9)$. Essentially we assume that in the case of a conflict between i and j, the import price of goods between i and j becomes $\frac{1}{0.7}$ times more expensive, while those between third countries and the two warring states are $\frac{1}{0.9}$ times more expensive. We compute the probabilities of conflicts between two core states, two peripheral states, and between a core and a peripheral state while increasing the number of cores in the network from 1 to N.

Equations (24) and (25) show that $\left\{\frac{S^P}{U_i^W}, \frac{U_j^W}{U_i^W}; V\right\}$ determine war probabilities for all pairs of states. For symmetric pairs, $\frac{S^P}{U_i^W}$ is equal to $2\frac{U_i^P}{U_i^W}$; while for asymmetric pairs, it is equal to $\frac{S^P}{U_i^P}\frac{U_i^P}{U_i^W}$. Under our benchmark calibration, $\frac{S^P}{U_i^P}$ is equal to $1+\frac{b_j}{b_i}$ based on equation (12). For all pairs, the ratio $\frac{U_j^W}{U_i^W}$ can be calculated using equations (14).

Figure 4 plots the evolution of $\frac{S^P}{U_i^W}$ for conflicts between the three distinct pairs as the number of cores increases. We can see that expected damages to the two cores in conflict decline sharply initially, and then slowly converges as n_c approaches 100.

The decline in expected damages to cores in conflict reflects a diversification mechanism. As the number of cores increases, any two cores depend less upon each other. As a result, the magnitude of initial war disruptions to bilateral trade becomes smaller. Moreover, their centralities decline as well, reducing their indirect damages to each other. Increases in the number of cores also lead to additional negative externalities. In particular, more cores would be affected through third party trade disruptions, potentially causing larger damages. This relates to the standard trade-off between connectivity and diversification in the transmission of microeconomic shocks through production networks (Acemoglu et al., 2012). However, under our current parameterization, the diversification mechanism prevails, resulting in a decline in expected damages to the two cores in conflict as the number of cores increases in

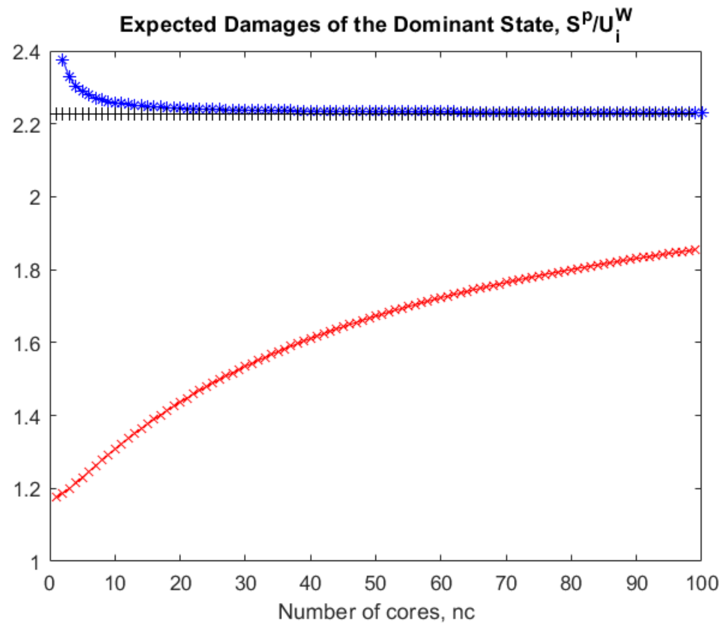


Figure 4: Expected damages as the number of cores increases. Core-Core (*), Periphery-Periphery (+), and Core-Periphery (x)

the network.[14]

Using equation (14), it is straightforward to show that the diversification and negative externalities arising from an increased number of cores exactly compensate each other in a periphery-periphery conflict. As a result, expected war damages to two peripheral states in conflict and their probabilities of war do not change as the number of cores increases. For the same degree of information asymmetry, probabilities of war between two core states are smaller than that between two peripheral ones.

The core-periphery conflict presents a different story. The ratio, $\frac{S^P}{U_i^W}$, is determined by $\frac{U_i^P}{U_i^W}$ and $\frac{S^P}{U_i^P}$. While $\frac{U_i^P}{U_i^W}$ would generally follow similar patterns of decline as the number of cores increases as in core-core and periphery-periphery conflicts, the ratio $\frac{S^P}{U_i^P}$ increases as the centrality of the dominant core state decreases. When the number of cores increases, the increase in $\frac{S^P}{U_i^P}$ dominates. Under our parameterization, $\frac{S^P}{U_i^W}$ remains well below the same ratio for the other two types of conflicts because $\frac{S^P}{U_i^P}$ is much smaller than 2 due to asymmetry.

Figure 5 shows probability of conflicts between core-core, periphery-periphery and core-periphery states when the number of cores is 2, 10 and 80. The horizontal axis represents V, the degree of information asymmetry, while the vertical axis represents the probability of

[14]We observe that it is possible for expected damages to two cores in conflict to increase as the number of cores goes up for particular parameterizations of μ and λ when n_c is less than 4.

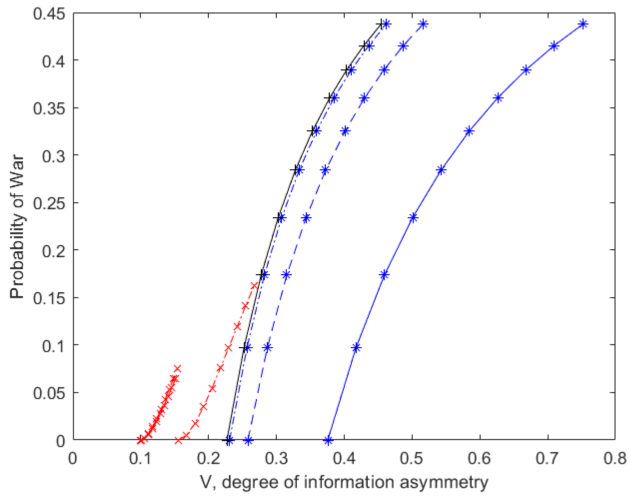


Figure 5: Probability of conflicts. Solid ($n = 2$), Dashed ($n = 10$), Dot-Dashed ($n = 80$). Core-Core(*), Periphery-Periphery(+), Core-Periphery(x)

conflicts conditional on both sides entering the bargaining stage. In the case of symmetric conflicts, first, consistent with Lemma 1, when the number of cores becomes higher, expected war damages decrease, the conditional probability of war becomes positive at a smaller V. Second, holding V fixed, probabilities of conflicts become smaller as expected damages increase, and conflicts between two peripheries are more likely than those between two cores.

The core-periphery pairs again present a different story. Given the lower expected damages to the dominant state compared with the symmetry case, a small degree of information asymmetry may lead to conflicts, but compared to the symmetry case, the probability of conflicts is capped even at the highest possible V, consistent with the illustration in Figure 2(b). [15]

Figure 5 shows two regions. When V exceeds a certain threshold relative to expected war damages, the probability of conflict between symmetric pairs is higher than that between asymmetric pairs for a broad range of V. Conversely, when V is sufficiently small relative to expected damages, the probability of any conflicts between symmetric states is zero.

[15] As the number of cores increase, the core and peripheral states become less asymmetric, and $\frac{S^P}{U_i^W}$ and $\frac{U_j^W}{U_i^W}$ both increase as a result. As shown in Lemma 2, these two ratios have opposite impacts on war probabilities. This explains why the curve that characterizes war probabilities shifts to the left of the bi-polar case when n_c is 10, which says that the effect of the increase in $\frac{U_j^W}{U_i^W}$ dominates that of the increase in $\frac{S^P}{U_i^W}$ for a certain V, but not always.

4 Empirical Evidence

Our theoretical model and numerical simulations indicate two important and empirically testable implications.

Testable implication 1: When expected war damages and the degree of information asymmetry are such that there are both symmetric and asymmetric conflicts, an increase in the asymmetry of the two states' relative network positions reduces the odds of conflict between the two.

This prediction is consistent with the illustration in Panels (a) and (b) of Figure 2, as well as the region in Figure 5 where expected damages are reasonably small relative to V so that both symmetric and asymmetric conflicts occur.

Testable implication 2: When expected war damages are too large relative to the degree of information asymmetry, asymmetry in the two states' relative network positions may not matter for the probability of conflicts.

This prediction holds in Panel (c) of Figure 2, where expected war damages to both are so large that the probability of war is zero, regardless of whether the two states are symmetric or not. It is also consistent with the region in Figure 5 where V is sufficiently small relative to expected damages such that the probability of war is either zero, or slightly positive when the dominant state gets an especially high outside option. In either case, asymmetry may not matter as much as in the situation in *Testable implication 1*

We use two major data sources to test these theoretical predictions. The first is the Correlates of War (COW) Project that contains a large array of data sets including interstate military conflicts, bilateral trade, contiguity and other country specific statistics. In the COW data, each militarized interstate conflict (MID) is coded according to the highest level of hostility in dyadic dispute. The code ranges from 1 to 5 (1 = No military action, 2 = Threat to use force. 3 = Display of force, 4 = Use of force, and 5 = war with at least 1000 deaths of military personnel). Examples of display of force (level 3) include mobilization, show of troops, ships and planes, and border fortification. Examples of use of force (level 4) include border violation, blockade, occupation of territory, clash and raid. The highest level of conflict, level 5, includes starting or joining an interstate war. Specifically, an interstate war is defined as a series of military battles that result in at least 1000 military deaths.[16] The second data source is the World Input-Output Database, which contains annual time series of input-output tables of 25 countries and regions from 1965 to 2000, and 43 countries

[16]For a state to be considered a participant in an interstate war, it must suffer at least 100 battle deaths, and deploy at least 1000 troops in battle-related activities.

and regions from 2000 to 2014.[17] These countries and regions are selected due to data availability of sufficient quality, as well as the fact that they cover a major part of the world economy. In particular, the 43 countries and regions cover more than 85% of world gross domestic product (GDP) in 2008 (at current exchange rates). The countries and regions not included in either period (1965-2000 or 2000-2014) are treated as "rest of the world" in both samples. Other data sources we use include GDP measures from the World Bank's World Development Index, and distance measures from the CEPII database.

	Full Sample		WIOD states	
Sample Size	721,422		38,780	
Frac. of Conflicts (%)	0.31		0.85	
Conflict Category	Frequency	%	Frequency	%
3	645	28.79	187	56.5
4	1,433	63.97	142	42.9
5	162	7.23	2	0.6
Total Conflicts	2240	100	331	100

Table 1: Conflict Patterns (1965-2014).

Table 1 shows that out of the full sample of 721,422 pair-year observations, only a very small fraction, 0.31 percent, involve military conflicts. The faction of military conflicts among WIOD states, on the other hand, is at 0.85 percent. Although WIOD states engage in relatively more conflicts, the majority of them are of level 3. The faction of level 5 conflicts, the costliest conflicts, is remarkably lower among WIOD states than the full sample. This pattern is consistent with our model predictions: WIOD states constitute a major fraction of world GDP, implying that expected damages from war can be larger due to their economic importance. Consequently, those states avoid costly conflicts at levels 4 and 5. The small number of level 5 conflicts inhibits robust estimates of probabilities of conflicts of the highest hostilities. Our empirical analysis adopts the broad definition of war that includes conflicts of level 3 and above. This definition, also adopted in Martin et al. (2008), fits our characterization of war as negative supply shocks that raise iceberg trading costs.

The World Input-Output Databases provide information on production costs and usage by both state and industry. We summarize across industries by each state to consolidate into a global input-output network by state. The data on value-added from intermediate

[17] The earlier sample covers 14 countries in Europe, 4 countries in North and South America (Canada, US, Mexico, and Brazil), 6 countries and regions in Asia (China, Hong Kong, Taiwan, Japan, South Korea, India), and Australia. The latter sample covers 28 European Union countries and 15 other major countries and regions. The latter sample includes all 25 countries and regions in the earlier set.

inputs and other factor inputs together with final usage of goods from all states allow us to construct the global adjacency matrix $\boldsymbol{G}$, the diagonal matrix of labor shares $\boldsymbol{\alpha}$, and the matrix of demand composition $\boldsymbol{\beta}$. We use the data from the WIOD to construct the matrix ofconsumption-weighted bilateral network exposures, $\boldsymbol{D}$, which is equal to $\boldsymbol{\beta}(\boldsymbol{I}-\boldsymbol{G})^{-1}$ as shown above.

Our theoretical model stresses the importance of asymmetry in network positions in affecting the probability of conflicts. In our empirical analysis, we construct a network measure, $|D_{i,j,t} - D_{j,i,t}|$, to capture the difference in mutual dependence between a pair of states. Here $D_{i,j,t}$ measures the direct and indirect effect on state $i's$ log utility given initial war disruptions to state j at period t. $D_{i,j,t}$ is high if state i's final consumption basket is heavily weighted toward goods of which state j is a relatively central supplier. Based on our network model, a higher $|D_{i,j,t} - D_{j,i,t}|$ proxies higher asymmetry in both peacetime and wartime utilities of the two states, thus a higher degree of asymmetry in mutual network dependence. Table E.1 in online Appendix E shows the summary statistics of $|D_{i,j,t} - D_{j,i,t}|$. The variable has its mean and standard deviation respectively at 0.018 and 0.032, and its minimum and maximum respectively at 0 and 0.39. The distribution is right skewed.[18]

Table E.2 in online Appendix E lists all military conflicts between US and China from 1965 to 2014 identified by the MID data set and corresponding network measures. The patterns of conflicts are broadly consistent with our model predictions. First, as China plays a more dominant role in the global network, expected damages from conflicts with the US become larger. As a result, both states engage in conflicts at a lower level of hostility as compared to the period between 1965 and 1971, when China was isolated from the global economy, and subject to limited expected war damages. Second, there were more conflicts when US and China were symmetric in mutual network dependence, both in the 1960s and after 1994, but fewer conflicts when China asymmetrically depended on the US between 1960s and 1990s.

We examine whether our model predictions hold in our broad WIOD sample of state pairs with a logit model. Our theoretical model generates the probability of a bilateral conflict conditional on two states entering into dispute. Since we only observe the final outcome, whether conflicts occurred or not, similar to Martin et al. (2008), we control for distance, contiguity, presence of historical conflicts between the two states, number of

[18]We can internalize these magnitudes by comparing them to our core-periphery example in the previous section. The measure is equal to 0 between two cores and two peripheral states. It is respectively 0.5 and 0.25 between a core and a periphery in a uni-core and bi-core network. In our global input-output network, US and Canada, US and Mexico, China and South Korea, Germany and Austria are among pairs of states featuring high degree of asymmetry in mutual network dependence in year 2014, where the latter state was far more dependent on the former, with the mutual dependence measure between 0.16 and 0.24.

peaceful years after the previous conflict, and interaction terms between distance and the measures of openness.[19] In addition, we construct a variable, $|D_{i,i,t} - D_{j,j,t}|$ to capture the expected damages to the dominant state, $\frac{S^P}{U_i^W}$. Here $D_{i,i,t}$ measures the direct and indirect effect on state $i's$ log utility given initial war disruption to itself. A high $D_{i,i}$ means that state i maintains a firm control of its own supply chain, thus more insulated from war disruptions. We also assign a dummy variable when one of the states has a permanent seat on the UN Security Council, and a dummy variable when China is involved in the conflict. The last two dummy variables are added because those states are disproportionately involved in military conflicts in our sample. Thus we condition the war occurrence on pair-specific heterogeneities that may affect occurrence of disputes. Our logit regression takes the following form:

$$log\left(\frac{Pr_{i,j,t}}{1-Pr_{i,j,t}}\right) = \gamma_0 + \gamma_1|D_{i,j,t-2} - D_{j,i,t-2}| + \gamma_2|D_{i,i,t-2} - D_{j,j,t-2}| + \gamma_3\text{controls}_{i,j,t} \quad (27)$$

We lag our network measures by two periods to limit contemporaneous reverse causality. We make the choice by investigating whether variations in our network measures "anticipate" a conflict by adding dummies for the four years preceding the conflict. The empirical results show minimum anticipatory adjustment in $|D_{i,j,t} - D_{j,i,t}|$ only one period prior to the conflict and no contemporary or anticipatory adjustments in $|D_{i,i,t} - D_{j,j,t}|$ in response to conflicts. This is understandable as adjustments of supply chains involve more than one state, and thus can take time.[20] We have to drop observations with missing variables in our regression. In total we have 18,251 pair-year observations in our benchmark regression.

Table 2 reports the regression results. Column (1) shows coefficients for predicted probabilities of conflicts at level 3 and above, and Column (2) shows corresponding coefficients for conflicts at level 4. There are in total 169 conflicts at level 3 and above, and 58 conflicts at level 4.[21] . As shown in Column (1), our measure of asymmetry in mutual network dependence, $|D_{i,j,t-2} - D_{j,i,t-2}|$, is significant at the 5.8% significance level. Specifically, for a one standard deviation increase in the variable, the odds of bilateral conflicts at level 3 and above happening are 78% of its previous value, holding other variables constant. Here the odds refer to the probability of a conflict occurring to it not occurring. Since we observe conflicts

[19] While we adopt Martin et al. (2008)'s concepts of bilateral and multilateral openness in principle, we calculate the measures differently. Instead of using the logarithm of the simple average of bilateral import flows over GDP as a measure of bilateral openness, we add 1 to the ratio of average import flows over GDP. This allows us to not exclude observations of pairs that have zero bilateral import flows when computing the logarithm of ratios. We implement the same procedure for the multilateral openness measure as well.

[20] The results are available upon request. Both network measures, $|D_{i,j,t} - D_{j,i,t}|$ and $|D_{i,i,t} - D_{j,j,t}|$, are highly persistent processes, with its first period lag explaining about 98 and 96 percent of their variances respectively.

[21] The only two conflicts at level 5 among the WIOD states drop out of the sample due to missing observations in the regression

Table 2: Regression Results

	(1) Mid3	(2) Mid4
$\lvert D_{i,j,t-2} - D_{j,i,t-2}\rvert$	-7.989*	5.278
	(-1.90)	(0.68)
$\lvert D_{i,i,t-2} - D_{j,j,t-2}\rvert$	1.338**	-1.053
	(2.03)	(-1.16)
bil_open_lag4	-173.*	-12.48
	(-1.69)	(-0.20)
mul_open_lag4	7.970	16.25
	(0.51)	(0.74)
histconf	4.391***	
	(8.92)	
peacehist	-0.126***	
	(-6.80)	
logdistw	0.229	0.993**
	(0.54)	(2.08)
cont	1.549***	1.921***
	(3.77)	(3.07)
distbil	24.50*	2.249
	(1.84)	(0.29)
distmul	-1.376	-2.341
	(-0.65)	(-0.82)
CHN	-0.386	1.824***
	(-1.28)	(3.14)
UN5	0.635	0.245
	(1.35)	(0.52)
histconf_4		2.638***
		(4.25)
peacehist_4		-0.0712***
		(-3.71)
cons	-8.660**	-15.41***
	(-2.45)	(-3.74)
N	18251	18251
Pseudo R^2	0.4368	0.3270

Notes: z statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. For Columns 1 (2), the dependent variable is a dummy variable that is equal to 1 when the highest level of hostility is coded 3 (4) and above. Variable bil_open is measured as the logarithm of one plus the simple average of bilateral import flows over each state's GDP, while mul_open as the logarithm of one plus the simple average of each state's imports from other third party states over its respective GDP. Variable logdistw denotes the logarithm of the distance measure from the CEPII database. The variables distbil and distmul are the interaction term of logdistw with bil_open and mul_open respectively. The variable cont is a dummy variable that is equal to 1 when the two states' territories are either separated by a land or river border, or by 400 miles of water or less with no third state in between. The variables histconf (histconf_4) are dummy variables that take value 1 if the two states have ever had a conflict since 1870, while peacehist (peacehist _4) denote years after conflicts at level 3 (4) and above. $UN5$ is a dummy variable that takes value 1 if one of the two states is a permanent member on the UN security council. CHN is a dummy variable if the bilateral conflict involves China. The variable cons denotes the constant term.

of Level 3 and above (predominantly Level 3 based on Table 1) between both symmetric and asymmetric pairs in the real world, an observation that implies a reasonably low expected damages relative to the degree of information asymmetry, Column (1) thus reports test results consistent with the environment in Testable Implication 1. The significantly negative coefficient of $|D_{i,j,t-2} - D_{j,i,t-2}|$ supports our testable theoretical implication that asymmetry in network positions reduces odds of conflicts. The implication is consistent with the smaller area of the obtuse triangle relative to the support of outside options in the asymmetric case in Figure 2(b), where the presence of the off ramp reveals information and reduces odds of conflicts.

Interestingly, the coefficient of $|D_{i,j,t-2} - D_{j,i,t-2}|$ becomes insignificantly different from zero in predicting probabilities of conflicts at level 4. This result, however, is consistent with our Testable implication 2. Conflicts at level 4 represent higher expected damages, and consequently, the probability of conflicts between relatively symmetric states may approach zero, and the only conflicts we may observe are rare occurrence of conflicts between two states that are highly asymmetric in network positions, when expected damages for the dominant state are low, and the draw for its outside option is unusually high. In such cases of high expected war damages, we may not observe the negative relationship between network asymmetry and odds of war. Column (2) of Table 2 reflects precisely such a situation.

Now turning to the rest of control variables, The variable, $|D_{i,i,t-2} - D_{j,j,t-2}|$ is significant at the 4.3% significance level in predicting the probability of conflicts at level 3 and above. The positive sign is intuitive as a higher $|D_{i,i,t-2} - D_{j,j,t-2}|$ implies a higher degree of self-dependence pertaining to the dominant state, and thus lower expected damages from the war. Specifically, for a one standard deviation increase in this measure, the odds of bilateral conflicts at level 3 and above happening are 1.33 times the odds before, holding other variables constant. The coefficient for the self-dependence measure is at about 10% significance level in predicting probabilities of conflicts at level 4 before we assign a dummy variable that indicates conflicts involving China. It becomes insignificant after the inclusion. China has a high degree of self-dependence, and a high probability of engaging in level 4 conflicts. Among the 58 conflicts of level 4, 30 of them involve China. The inclusion of the China dummy takes away the predictive power of the self-dependence measure.

Similar to Martin et al. (2008), an increase in bilateral openness four years prior to conflicts reduces the probability of conflicts at level 3 and above, but less so for distant states. Similarly, we also find that whether two states have ever engaged in military conflicts, the number of years after the previous conflict and contiguity are significant in predicting war probabilities in both Column (1) and (2) regressions, both with intuitive signs.[22] However, with the WIOD sample, the multilateral openness measure of Martin et al. (2008) becomes insignificant in Column (1), but our two network measures are statistically significant. Both our network measures as well as the bilateral and multilateral openness measures have insignificant coefficients for predicting level 4 conflicts.

We conduct further robustness checks, including varying lags, adding political controls, and controlling for dyad fixed effects and time dummies, our findings on the negative effect of asymmetry in network positions remain robust in those alternative settings. We also run regressions that exclude our network measures using samples including all states and only WIOD states respectively. Our regression on the sample including all states confirms the main empirical findings of Martin et al (2008). However, their measure of multi-country openness is no longer significant in the sample containing only WIOD states, while as shown in Table 2, both of our network measures are robust using the WIOD sample. All results of robustness checks are contained in Table E.3.

In summary, the empirical evidence broadly supports our theoretical framework on the relationship between the global input-output network and bilateral probabilities of conflicts.

5 Conclusion

To our knowledge, our paper is the first to establish a micro-foundation that explicitly links a weighted and directed production network to bilateral probabilities of military conflicts. To that end, we generalize the bargaining framework proposed by Compte and Jehiel (2004, 2009) to accommodate bargaining between states that are asymmetric as well as symmetric in their network positions. Contrary to previous work, we find that it is not merely the amount of total trade, but the characteristics of the global production network –in particular, the pairwise relative positions in mutual network dependence – that matter for the bilateral probability of conflicts. We show that higher asymmetry in mutual network dependence can reveal information and reduce the odds of conflicts. We also provide empirical evidence in support of this channel.

By providing both theoretical and empirical evidence for adopting a global input-output network perspective, our research opens new avenues for understanding the intersection of global networks, trade, and conflict probabilities. Our model contributes to crucial policy discussions by explicitly linking the architecture of the global production network to bilateral conflict probabilities. Such characterization is the first step toward understanding how

[22]We follow Martin et al's (2008) in taking a four-year lag for bilateral and multilateral openness measures in our regression to deal with the endogeneity issue.

forming alternative networks, for example, through decoupling and fragmentation, would affect welfare from trade and probabilities of war. Our work also sheds light on third-party interventions in the bargaining process by states not directly involved in the conflicts. These are fruitful directions for future research.

References

[1] Acemoglu, Daron, Vasco M. Carvalho, Asuman Ozdaglar, and Alireza Tahbaz-Salehi. "The network origins of aggregate fluctuations." Econometrica 80, no. 5 (2012): 1977-2016.

[2] Antras, Pol, and Davin Chor. "On the measurement of upstreamness and downstreamness in global value chains." World Trade Evolution: Growth, Productivity and Employment 5 (2018): 126-194.

[3] Armington, Paul S. "A Theory of Demand for Products Distinguished by Place of Production." Staff Papers-International Monetary Fund (1969): 159-178.

[4] Bailey, Michael A., Anton Strezhnev, and Erik Voeten. "Estimating dynamic state preferences from United Nations voting data." Journal of Conflict Resolution 61.2 (2017): 430-456.

[5] Barbieri, Katherine. The liberal illusion: Does trade promote peace?. University of Michigan Press, 2002.

[6] Barbieri, Katherine and Omar M. G. Omar Keshk. 2016. Correlates of War Project Trade Data Set Codebook, Version 4.0. Online: http://correlatesofwar.org.

[7] Barbieri, Katherine, Omar M. G. Keshk, and Brian Pollins. 2009. "TRADING DATA: Evaluating our Assumptions and Coding Rules." Conflict Management and Peace Science, 26(5): 471-491.

[8] Baqaee, David, and Emmanuel Farhi. Networks, barriers, and trade. No. w26108. National Bureau of Economic Research, 2019.

[9] Blainey, Geoffrey. Causes of war. Simon and Schuster, 1988.

[10] Bonacich, Phillip. "Power and centrality: A family of measures." American journal of sociology 92, no. 5 (1987): 1170-1182.

[11] Caliendo, Lorenzo, and Fernando Parro. "Estimates of the Trade and Welfare Effects of NAFTA." The Review of Economic Studies 82, no. 1 (2015): 1-44.

[12] Clayton, Christopher, Matteo Maggiori, and Jesse Schreger. A framework for geoeconomics. No. w31852. National Bureau of Economic Research, 2023.

[13] Compte, Olivier, and Philippe Jehiel. "Veto constraint in mechanism design: inefficiency with correlated types." American Economic Journal: Microeconomics 1, no. 1 (2009): 182-206.

[14] Compte, Olivier, and Philippe Jehiel. "Inefficiencies in bargaining-departing from Akerlof and Myerson-Satterthwaite." (2004).

[15] Copeland, Dale C. "Economic interdependence and war: A theory of trade expectations." International security 20, no. 4 (1996): 5-41.

[16] Correlates of War Project. Direct Contiguity Data, 1816-2016. Version 3.2.

[17] Di Giovanni, Julian, Andrei A. Levchenko, and Jing Zhang. "The global welfare impact of China: Trade integration and technological change." American Economic Journal: Macroeconomics 6, no. 3 (2014): 153-183.

[18] Fearon, James D. "Rationalist explanations for war." International organization 49, no. 3 (1995): 379-414.

[19] Jackson, Matthew O., and Stephen Nei. "Networks of military alliances, wars, and international trade." Proceedings of the National Academy of Sciences 112, no. 50 (2015): 15277-15284.

[20] Jackson, Matthew O., and Massimo Morelli. The reasons for wars: an updated survey. Edward Elgar, 2011.

[21] Kleinman, Benny, Ernest Liu, and Stephen J. Redding. International friends and enemies. American Economic Journal: Macroeconomics, forthcoming.

[22] Korovkin, Vasily, and Alexey Makarin. "Production networks and war: Evidence from Ukraine." Available at SSRN 3969161 (2022).

[23] Long Jr, John B., and Charles I. Plosser. "Real business cycles." Journal of political Economy 91, no. 1 (1983): 39-69.

[24] Mansfield, Edward D. Power, trade, and war. Princeton University Press, 1995.

[25] Zeev Maoz, Paul L. Johnson, Jasper Kaplan, Fiona Ogunkoya, and Aaron Shreve 2019. The Dyadic Militarized Interstate Disputes (MIDs) Dataset Version 3.0: Logic, Characteristics, and Comparisons to Alternative Datasets, Journal of Conflict Resolution, 6(3) 811-835.

[26] Martin, Philippe, Thierry Mayer, and Mathias Thoenig. "Make trade not war?." The Review of Economic Studies 75, no. 3 (2008): 865-900.

[27] Mayer, T. and S. Zignago (2006), "Notes on CEPII's distance measures", MPRA Paper 31243.

[28] Myerson, Roger B., and Mark A. Satterthwaite. "Efficient mechanisms for bilateral trading." Journal of economic theory 29, no. 2 (1983): 265-281.

[29] Glenn Palmer, Vito D'Orazio, Michael Kenwick and Matthew Lane. 2015. The MID4 Data Set, 2002-2010. Conflict Management and Peace Science, 32(2), pp. 222-242.

[30] Polachek, Solomon William. "Conflict and trade." Journal of conflict resolution 24, no. 1 (1980): 55-78.

[31] Polachek, Solomon W., and Judith McDonald. "Strategic trade and the incentive for cooperation." Disarmament, economic conversion, and management of peace (1992): 273-284.

[32] Sargent, Thomas J., and John Stachurski. "Economic Networks: Theory and Computation." arXiv preprint arXiv:2203.11972 (2022).

[33] Singer, J. David, Stuart Bremer, and John Stuckey. (1972). "Capability Distribution, Uncertainty, and Major Power War, 1820-1965." in Bruce Russett (ed) Peace, War, and Numbers, Beverly Hills: Sage, 19-48.

[34] Singer, J. David. 1987. "Reconstructing the Correlates of War Dataset on Material Capabilities of States, 1816-1985" International Interactions, 14: 115-32.

[35] Douglas M. Stinnett, Jaroslav Tir, Philip Schafer, Paul F. Diehl, and Charles Gochman (2002). "The Correlates of War Project Direct Contiguity Data, Version 3." Conflict Management and Peace Science 19 (2): 58-66.

[36] Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R. and de Vries, G. J. (2015), "An Illustrated User Guide to the World Input-Output Database: the Case of Global Automotive Production" , Review of International Economics., 23: 575â605

[37] Woltjer, P., Gouma, R. and Timmer, M. P. (2021), "Long-run World Input-Output Database: Version 1.1 Sources and Methods", GGDC Research Memorandum 190

[38] World Bank, World Development Indicators.

Appendix

A. Proofs of Main Theorems

Proof of Theorem 1

We start by recalling the definitions of $a(\tilde{U}_k^W)$ and $h(\tilde{U}_i^W)$:

$$a(\tilde{U}_k^W) = v_k + \frac{1}{4}(S^P - v_i - v_j) + \frac{2}{3}(\tilde{U}_k^W - v_k)$$
$$h(\tilde{U}_i^W) = a(\tilde{U}_i^W + Q(\tilde{U}_i^W))$$

where

$$Q(\tilde{U}_i^W) = max\left(Q + \left(\frac{U_j^W}{U_i^W} - 1\right)\left(\tilde{U}_i^W - v_i\right), 0\right)$$

and

$$Q = \frac{3}{4}(S^P - v_i - v_j) - \frac{3}{2}VU_j^W$$

Moreover, recall that from the distribution of outside options we have $v_k = (1 - \frac{V}{2})U_k^W$, $\bar{v}_k = (1+V)U_k^W$, $\overline{V}_i = \bar{v}_i + v_j$, and $\overline{V}_j = \bar{v}_j + v_i$. Given $R = \frac{3}{4}S^P + \frac{1}{4}(v_i + v_j) < \overline{V}_j$, we have the following relation between Q and R:

$$Q = R - (v_i + v_j) - \frac{3}{2}VU_j^W \tag{A.1}$$

Without loss of generality we are assuming $U_i^W \geq U_j^W$. We prove each case separately.

CASE I: $R \leq \min\left(\overline{V}_i, \overline{V}_j\right)$

Given equation A.1 and that $\frac{U_j^W}{U_i^W} \leq 1$, we have

$$\begin{aligned} Q + \left(\frac{U_j^W}{U_i^W} - 1\right)\left(\tilde{U}_i^W - v_i\right) &\leq Q \\ &= R - (v_i + v_j) - \frac{3}{2}VU_j^W \\ &\leq \overline{V}_j - (v_i + v_j) - \frac{3}{2}VU_j^W \\ &= 0 \end{aligned}$$

The preceding inequality implies that in Case I,

$$h(\tilde{U}_i^W) = a(\tilde{U}_i^W.)$$

Proving the result thus reduces to showing that the strategy profile

$$(\hat{U}_i^{W*}, \hat{U}_j^{W*}) = (a(\tilde{U}_i^W), a(\tilde{U}_j^W))$$

constitutes a Bayesian-Nash equilibrium. The proof is provided by Compte and Jehiel (2004, 2009), and later adapted in Martin, Mayer and Thoenig (2008).

CASE II: $\overline{V}_j \leq R < \overline{V}_i$

We start by recalling the equation,

$$\eta_i\left(\tilde{U}_j^W\right) = v_i + \bar{v}_i - \frac{U_i^W}{U_j^W}\tilde{U}_j^W$$

where $\eta_i\left(\tilde{U}_j^W\right)$ represents the maximum value $\tilde{U}_i^W$ can take for any given $\tilde{U}_j^W$ based on the distribution of outside options. We make the following claims:

Claim 1. $a(\tilde{U}_j^W) + h\left(\eta_i\left(\tilde{U}_j^W\right)\right) = S^P$ and $a\left(\eta_j\left(\tilde{U}_i^W\right)\right) + h\left(\tilde{U}_i^W\right) = S^P$

Proof of Claim 1

Given the definitions of the $a(.)$ and $h(.)$, for any pairs of $\{\tilde{U}_i^W, \tilde{U}_j^W\}$, the following equivalence holds:

$$a(\tilde{U}_j^W) + h(\tilde{U}_i^W) = S^P \iff \tilde{U}_j^W + \tilde{U}_i^W + Q(\tilde{U}_i{}^W) = R$$

Now we show that when $\tilde{U}_i^W = \eta_i\left(\tilde{U}_j^W\right)$, the right hand side of the equivalence result holds. Specifically,

$$\begin{aligned}\tilde{U}_j^W + \eta_i\left(\tilde{U}_j^W\right) + Q\left(\eta_i\left(\tilde{U}_j^W\right)\right) &= \tilde{U}_j^W + \eta_i\left(\tilde{U}_j^W\right) + Q + \left(\frac{U_j^W}{U_i^W} - 1\right)\left(\eta_i\left(\tilde{U}_j^W\right) - v_i\right) \\ &= R\end{aligned}$$

The last equality makes use of equation (A.1). We thus establish the fact that $a(\tilde{U}_j^W) + h\left(\eta_i\left(\tilde{U}_j^W\right)\right) = S^P$. A similar argument shows that $a\left(\eta_j\left(\tilde{U}_i^W\right)\right) + h\left(\tilde{U}_i^W\right) = S^P$

■

The rest of the proof of Case II is broken down in two claims.

Claim 2. Given $h(\tilde{U}_i^W)$, state $j's$ best response is $a(\tilde{U}_j^W)$

Proof of Claim 2

The proof of Claim 2 is different depending on whether the realization of $\tilde{U}_j^W$ is above or below a certain threshold. As shown in Figure 2(b), the coordinate $\{\bar{X}, \bar{Y}\}$, which marks the intersection of the threshold line, $a(\tilde{U}_j^W) + h(\tilde{U}_i^W) = S^P$ and the hypotenuse of the triangle enclosing outside options, satisfies the following two conditions:

$$Q(\bar{X}) = 0, \bar{Y} = \eta_j \left(\bar{X}\right)$$

It is straightforward to show that $Q(\tilde{U}_i^W) > 0$ if and only if $\tilde{U}_i^W < \bar{X}$.

Step 1: If $\tilde{U}_j^W > \bar{Y}$, $a(\tilde{U}_j^W)$ is a best response to $h(\tilde{U}_i^W)$

In this case, we have $Q(\tilde{U}_i^W) > 0$ since the highest possible $\tilde{U}_i^W$ is lower than $\bar{X}$. To prove the optimality, we show that the interim payoff is strictly increasing in $\hat{U}_j^W$ when $\hat{U}_j^W \leq a(\tilde{U}_j^W)$, and $\frac{\partial G_j(\hat{U}_j^W, \tilde{U}_j^W)}{\partial \hat{U}_j^W} \leq 0$ for all $\hat{U}_j^W \geq a(\tilde{U}_j^W)$, where $G_j(\hat{U}_j^W, \tilde{U}_j^W)$ represents the interim payoff for state j with the outside option $\tilde{U}_j^W$. We thus establish that $a(\tilde{U}_j^W)$ dominates all other responses while not triggering conflicts when $\tilde{U}_j^W > \bar{Y}$. This is the "off ramp" we describe in the text.

When $\hat{U}_j^W \leq a(\tilde{U}_j^W)$, we have the following inequality given Claim 1:

$$\hat{U}_j^W + h\left(\eta_i\left(\tilde{U}_j^W\right)\right) \leq a(\tilde{U}_j^W) + h\left(\eta_i\left(\tilde{U}_j^W\right)\right) = S^P.$$

Since $\eta_i\left(\tilde{U}_j^W\right)$ is the maximum $\tilde{U}_i^W$ given $\tilde{U}_j^W$, this implies that for all $\hat{U}_j^W \leq a(\tilde{U}_j^W)$, $a(\tilde{U}_j^W)$ is the maximum that state j can ask without triggering war. Moreover, since the interim payoff is strictly increasing in $\hat{U}_j^W$ when war is not triggered, $a(\tilde{U}_j^W)$ dominates any other $\hat{U}_j^W$ in the region $\hat{U}_j^W \leq a(\tilde{U}_j^W)$

When $\hat{U}_j^W > a(\tilde{U}_j^W)$, conditional on state i following $h(\tilde{U}_i^W)$, state $j's$ announcement will induce a positive probability of war. Using the expression of $\Phi_j(.)$ in Definition 2, State j's interim objective can be given by

$$G_j(\hat{U}_j^W, \tilde{U}_j^W) = \int_{v_i}^{R_i(\hat{U}_j^W)} \left(\frac{S^P + \hat{U}_j^W - h(\tilde{U}_i^W)}{2}\right) df(\tilde{U}_i^W|\tilde{U}_j^W) + \int_{R_i(\hat{U}_j^W)}^{\eta_i(\tilde{U}_j^W)} \tilde{U}_j^W df(\tilde{U}_i^W|\tilde{U}_j^W), \tag{A.2}$$

where $R_i(\hat{U}_j^W)$ is defined as the threshold value of $\tilde{U}_i^W$ such that given $\hat{U}_j^W$, war is triggered when $\tilde{U}_i^W > R_i(\hat{U}_j^W)$. Specifically,

$$h(R_i(\hat{U}_j^W)) + \hat{U}_j^W = S^P,$$

which yields

$$v_i + \frac{3}{2}\frac{U_i^W}{U_j^W}\left[S^P - \hat{U}_j^W - v_i - \frac{1}{4}(S^P - (v_i + v_j))\right] - \frac{U_i^W}{U_j^W}Q \equiv R_i(\hat{U}_j^W).$$

Differentiating with respect to $\hat{U}_j^W$ and using Leibniz's rule yields:

$$\begin{aligned}\frac{\partial G_j(\hat{U}_j^W, \tilde{U}_j^W)}{\partial \hat{U}_j^W} &= \frac{S^P}{2}R_i'(\hat{U}_j^W) + \frac{R_i'(\hat{U}_j^W)\hat{U}_j^W}{2} + \frac{R_i(\hat{U}_j^W) - v_i}{2} - \tilde{U}_j^W R_i'(\hat{U}_j^W) - R_i'(\hat{U}_j^W)\frac{h(R_i(\hat{U}_j^W))}{2} \\ &= R_i'(\hat{U}_j^W)K_i(\hat{U}_j^W),\end{aligned}$$

where

$$K_i(\hat{U}_j^W) = \frac{S^P}{2} + \frac{\hat{U}_j^W}{2} + \frac{R_i(\hat{U}_j^W) - v_i}{2R_i'(\hat{U}_j^W)} - \tilde{U}_j^W - \frac{h(R_i(\hat{U}_j^W))}{2}.$$

Given that $R'(\hat{U}_j^W) = -\frac{3}{2}\frac{U_i^W}{U_j^W} < 0$, showing that $K(\hat{U}_j^W) > 0$ for all $\hat{U}_j^W > a(\tilde{U}_j^W)$ establishes that $a(\tilde{U}_j^W)$ is a best response in this region as well. We can show that

$$\frac{\partial G_j(\hat{U}_j^W, \tilde{U}_j^W)}{\partial \hat{U}_j^W} = 0 \iff K(\hat{U}_j^W) = 0 \iff \hat{U}_j^W = a(\tilde{U}_j^W) - \frac{2}{9}Q$$

Moreover, it holds that $K_i'(\hat{U}_j^W) > 0$. Since $a(\tilde{U}_j^W) > a(\tilde{U}_j^W) - \frac{2}{9}Q$, we have $K_i(a(\tilde{U}_j^W)) > 0$ and thus $\frac{\partial G(\hat{U}_j^W, \tilde{U}_j^W)}{\partial \hat{U}_j^W} < 0$ for all $\hat{U}_j^W > a(\tilde{U}_j^W)$. In other words, asking for more than $a(\tilde{U}_j^W)$ not only triggers war, but gives state j a lower expected payoff. Consequently, it is optimal to follow $a(\tilde{U}_j^W)$.

Step 2: If $\tilde{U}_j^W < \tilde{U}_j^{W,B}$, then $a(\tilde{U}_j^W)$ is still a best response to $h(\tilde{U}_i^W)$

In this case, state j does not know whether $Q(\tilde{U}_i^W)$ is positive of zero. However, it knows that if $\tilde{U}_i^W \leq \bar{X}$ then state i will announce $a(\tilde{U}_i^W + Q(\tilde{U}_i^W))$, whereas if $\tilde{U}_i^W > \bar{X}$ then state i will announce $a(\tilde{U}_i^W)$. To derive state $j's$ best response, we can use the fact that its interim payoff is dependent on whether $R_i(\tilde{U}_j^W)$ is above or below $\bar{X}$. We show that $a(\tilde{U}_j^W)$ dominates all $\hat{U}_j^W$ that are sufficiently small such that $R_i(\hat{U}_j^W) \geq \bar{X}$. We also show that $\frac{\partial G(\hat{U}_j^W, \tilde{U}_j^W)}{\partial \hat{U}_j^W} \leq 0$ for all $\hat{U}_j^W$ that are sufficiently large such that $R(\hat{U}_j^W) \leq \bar{X}$, following the same derivations as in Step 1. We thus establish the dominance of $a(\tilde{U}_j^W)$. Specifically, conditional on $R_i(\hat{U}_j^W)$ being above or below $\bar{X}$, we have

$$G_j(\hat{U}_j^W, \tilde{U}_j^W)\Big|_{R_i(\hat{U}_j^W)\geq \bar{X}} = \int_{v_i}^{\bar{X}} \left(\frac{S^P + \hat{U}_j^W - a(\tilde{U}_i^W + Q(\tilde{U}_i^W))}{2}\right) df(\tilde{U}_i^W|\tilde{U}_j^W) + \int_{\bar{X}}^{R_i(\hat{U}_j^W)} \left(\frac{S^P + \hat{U}_j^W - a(\tilde{U}_i^W)}{2}\right) df(\tilde{U}_i^W|\tilde{U}_j^W) + \int_{R_i(\hat{U}_j^W)}^{\eta_i(\tilde{U}_j^W)} \tilde{U}_j^W df(\tilde{U}_i^W|\tilde{U}_j^W)$$

whereas $G_j(\hat{U}_j^W, \tilde{U}_j^W)\Big|_{R_i(\hat{U}_j^W)\leq \bar{X}}$ is the same as the objective function in equation (A.2) in Step 1. As a result, $\frac{\partial G_j(\hat{U}_j^W, \tilde{U}_j^W)}{\partial \hat{U}_j^W}\Big|_{R_i(\hat{U}_j^W)\leq \bar{X}} < 0$ holds for all $\hat{U}_j^W$ satisfying the latter criteria.

The strategy $a(\tilde{U}_j^W)$ belongs to the range $R_i(\hat{U}_j^W) \geq \bar{X}$ because there exists a $\tilde{U}_i^W \geq \bar{X}$ such that

$$h(\tilde{U}_i^W) + a(\tilde{U}_j^W) = S^P,$$

we also have

$$\frac{\partial G_j(\hat{U}_j^W, \tilde{U}_j^W)}{\partial \hat{U}_j^W}\Bigg|_{R_i(\hat{U}_j^W)\geq \tilde{U}_i^{W,B}} = 0 \iff \hat{U}_j^W = a(\tilde{U}_j^W)$$

.

We thus establish that $a(\tilde{U}_j^W)$ is optimal regardless of whether $R_i(\hat{U}_j^W)$ is above or below $\bar{X}$.

■

Claim 3. Given $a(\tilde{U}_j^W)$, state $i's$ best response is $h(\tilde{U}_i^W)$

Proof of Claim 3

The proof is similar to that in Step 1 of Claim 2. We show that the interim payoff is strictly increasing in $\hat{U}_i^W$ when $\hat{U}_i^W \leq h(\tilde{U}_i^W)$, and $\frac{\partial G_i(\hat{U}_i^W, \tilde{U}_i^W)}{\partial \hat{U}_i^W} \leq 0$ for all $\hat{U}_i^W \geq h(\tilde{U}_i^W)$, where $G_i(\hat{U}_i^W, \tilde{U}_i^W)$ represents the interim payoff for state i with the outside option $\tilde{U}_i^W$. We thus establish that $h(\tilde{U}_i^W)$ dominates all other responses.

When $\hat{U}_i^W \leq h(\tilde{U}_i^W)$, we have the following inequality following Claim 1:

$$\hat{U}_i^W + a\left(\eta_j\left(\tilde{U}_i^W\right)\right) \leq h\left(\tilde{U}_i^W\right) + a\left(\eta_j\left(\tilde{U}_i^W\right)\right) = S^P$$

since $\eta_j\left(\tilde{U}_i^W\right)$ is the maximum $\tilde{U}_j^W$ given $\tilde{U}_i^W$, this implies that for all $\hat{U}_i^W \leq h(\tilde{U}_i^W)$, $h(\tilde{U}_i^W)$ is the maximum that state i can ask without triggering war. Moreover, since the interim payoff is strictly increasing in $\hat{U}_i^W$ when war is not triggered, $h(\tilde{U}_i^W)$ dominates any other

$\hat{U}_i^W$ in the region $\hat{U}_i^W \leq h(\tilde{U}_i^W)$.

When $\hat{U}_i^W > h(\tilde{U}_i^W)$, conditional on state j following $a(\tilde{U}_j^W)$, state $i's$ announcement will induce a positive probability of war. Using the expression of $\Phi_i(.)$ in Definition 2, State i's interim objective can be rewritten as

$$G_i(\hat{U}_i^W, \tilde{U}_i^W) = \int_{v_j}^{R_j(\hat{U}_i^W)} \left(\frac{S^P + \hat{U}_i^W - a(\tilde{U}_j^W)}{2} \right) df(\tilde{U}_j^W|\tilde{U}_i^W) + \int_{R_j(\hat{U}_i^W)}^{\eta_j(\tilde{U}_i^W)} \tilde{U}_i^W df(\tilde{U}_j^W|\tilde{U}_i^W),$$

where $R_j(\hat{U}_i^W)$ is defined as the threshold value of $\tilde{U}_j^W$ such that given $\hat{U}_i^W)$, war is triggered when $\tilde{U}_j^W) > R_j(\hat{U}_i^W)$. Specifically,

$$\hat{U}_i^W + a(R_j(\hat{U}_i^W) = S^P,$$

which yields

$$v_j + \frac{3}{2}\left[S^P - \hat{U}_i^W - v_j - \frac{1}{4}(S^P - (v_i + v_j))\right] \equiv R_j(\hat{U}_i^W)$$

Differentiating with respect to $\hat{U}_i^W$ yields:

$$\frac{\partial G_i(\hat{U}_i^W, \tilde{U}_i^W)}{\partial \hat{U}_i^W} = R_j'(\hat{U}_i^W) k_j(\hat{U}_i^W)$$

where

$$k_j(\hat{U}_i^W) = \frac{S^P}{2} + \frac{\hat{U}_i^W}{2} + \frac{R_j(\hat{U}_i^W) - v_i}{2R_j'(\hat{U}_i^W)} - \tilde{U}_i^W - \frac{a(R_j(\hat{U}_i^W))}{2}$$

Observe that since $R_j'(\hat{U}_i^W) < 0$, then showing that $k_j(\hat{U}_i^W) > 0$ for all $\hat{U}_i^W > h(\tilde{U}_i^W)$ establishes that $h(\tilde{U}_i^W)$ is a best response in this region as well. We can show that

$$\frac{\partial G_i(\hat{U}_i^W, \tilde{U}_i^W)}{\partial \hat{U}_i^W} = 0 \iff k_j(\hat{U}_i^W) = 0 \iff \hat{U}_i^W = a(\tilde{U}_i^W)$$

Moreover, it holds that $k_j'(\hat{U}_i^W) > 0$. Since $h(\tilde{U}_i^W) > a(\tilde{U}_i^W)$, this implies that $k_j(\hat{U}_i^W) > 0$ for all $\hat{U}_i^W > h(\tilde{U}_i^W)$ and thus $\frac{\partial G_i(\hat{U}_j^W, \tilde{U}_j^W)}{\partial \hat{U}_j^W} < 0$ for all $\hat{U}_i^W > h(\tilde{U}_i^W)$. In other words, asking for more than $h(\tilde{U}_i^W)$ not only triggers war, but gives state i a lower expected payoff. Consequently, it is optimal to follow $h(\tilde{U}_i^W)$.

■

In summary, Claims 2 and 3 show that the strategy profile $(h(\tilde{U}_i^W), a(\tilde{U}_j^W))$ constitutes a tuple of mutual best responses and hence a Bayesian-Nash equilibrium of the bargaining game in Case II.

CASE III

Lastly, suppose that $R \geq max(\overline{V}_i, \overline{V}_j)$. In this case, for any $\tilde{U}_j^W$ it always holds that $Q(\tilde{U}_i^W) > 0$. Therefore, the same arguments that establish Claim 2 Step 1 and Claim 2 show that the strategy profile $(h(\tilde{U}_i^W), a(\tilde{U}_j^W))$ constitutes a tuple of mutual best responses, and hence a Bayesian-Nash equilibrium of the bargaining game in Case III as well.

■

Proof of Theorem 2

Since the distribution of outside options can be represented by a triangular region in (U_i, U_j) space with vertices at (v_i, v_j), $(v_i, \bar{v}_j)$, and $(\bar{v}_i, v_j)$, then computing the probability of war reduces to calculating the value of a ratio $\frac{\mu(\mathcal{D} \cap \mathcal{O})}{\mu(\mathcal{O})}$ where $\mu(\mathcal{D} \cap \mathcal{O})$ is the area of the polygon enclosing the region of (U_i, U_j) space generated by intersecting $\mathcal{D}$ and $\mathcal{O}$ (see Figure 2), and where $\mu(\mathcal{O})$ is the area of the triangle support $\mathcal{O}$ given by $\mu(\mathcal{O}) = \frac{1}{2}\frac{9}{4}V^2 U_i^W U_j^W$.

Case I is established in Martin et al. (2008).[23] For Case III, observe that the condition $R \geq max(\overline{V}_i, \overline{V}_j)$ implies that $\mathcal{D} \cap \mathcal{O} = \emptyset$ and hence the probability of war is zero.

In Case II, the polygon enclosing the region of (U_i, U_j) space generated by intersecting $\mathcal{D}$ and $\mathcal{O}$, is an obtuse triangle (Figure 2 panel (b)) with vertices at (G_x, G_y), (A_x, A_y), and $(\bar{v}_i, v_j)$. Here vertex (G_x, G_y) is the point at which the hypotenuse of $\mathcal{O}$ intersects the threshold R, and is consequently the solution to the system of equations (i) $G_x + G_y = R$, and (ii) $\frac{G_y - v_j}{\frac{3}{2}VU_j^W} = \frac{\bar{v}_i - G_x}{\frac{3}{2}VU_i^W}$. Similarly, vertex (A_x, A_y) is the point at which the horizontal line $U_j = v_j$ intersects the threshold R, and consequently satisfies (i) $A_y = v_j$, and (ii) $A_x + A_y = R$. Solving both systems, computing the area of the resulting obtuse triangle, and dividing by $\mu(\mathcal{O})$ gives the result.

■

B. Data Sources

We use the Dyadic MID data V4.02, which is part of the COW Project, to compile data on states involved in conflicts, classifications of military conflicts and years after conflicts from 1965 to 2014. We clean the data set so that the conflicts in the sample are undirected. The COW Trade data V4.0 is used to construct bilateral trade flows between states and each states' total imports from 1965-2014. GDP data for the sample period come from the World Bank's WDI database. The distance measure, distw, comes from the CEPII's *GeoDist* database. We use Version 3.2 of the Correlates of War Direct Contiguity data to identify the contiguity relationships between states. The World Input-Output Database (WIOD)

[23] Note that equation 3 in Martin et al. (2008) is a special case of our Case I, that is, when $V = 2$. Our formula holds for any admissible V as long as the condition $R \leq \min\left(\overline{V}_i, \overline{V}_j\right)$ holds.

November 2016 Release covers 28 EU countries and 15 other major countries and regions in the world for the period from 2000 to 2014. The Long-run WIOD covers 25 countries and regions for the period 1965-2000. For robustness checks, we use the difference in ideal point estimates by Bailey, Strezhnev and Voeten (2017) to capture the difference in UN voting patterns between two states (UN_votes_diff) over time. We use the polity score constructed in the Polity V project to create the variable, polity_min, which represents the lower polity score of each dyad. Here the polity score is a composite index ranging from -10 (strongly autocratic) to $+10$ (strongly democratic). The area measure, area_max, which reports the area of the state with a larger territory, comes from the CEPII's *GeoDist* database.

Online Appendix to "Trade and War: A Global Input-Output Network Perspective"

Hector Tzavellas Chao Wei

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Abstract

This online appendix is organized as follows. Online Appendix C provides the proof that the bargaining protocol is second best. Online Appendix D derives the equilibrium of the trade model. Online Appendix E provides additional tables and robustness checks. Online Appendix F contains the proofs of Lemmas 1 and 2.

C. Second Best

We follow the same strategy as proposed by Compte and Jehiel (2004, 2009), and adopted in Appendix A2 of Martin et al. (2008) in showing that the Nash Bargaining protocol in our model implements the second best outcome, which maximizes expected total gains from bargaining under the assumption of incentive compatibility and individual rationality. A direct application of Myerson and Satterthwaite's (1983) Thoerem 2 indicates that for a buyer and a seller with private valuations uniformly distributed on the square $[0, S^p - v_i - v_j] \times [0, S^p - v_i - v_j]$, the second best is implemented by a mechanism that transfers the

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object if and only if the buyer's valuation exceeds the seller's by at least $\frac{1}{4}\left(S^p - v_i - v_j\right)$, that is, one fourth of the maximum possible gain from trade.

Compte and Jehiel (2004, 2009) show that the bargaining problem in our model can be recast into Myerson and Satterthwaite's (1983) buyer-seller problem, where one of the state's outside option, say $\widetilde{U}_i^W - v_i$, can be considered as the private valuation of the seller, while $(S^p - v_i - v_j) - (\widetilde{U}_j^W - v_j)$, can be considered as the private valuation of the buyer. As a result, when the buyer's and the seller's private valuations, and consequently $\left\{\widetilde{U}_i^W, \widetilde{U}_j^W\right\}$, are uniformly distributed on the square $[0, S^p - v_i - v_j] \times [0, S^p - v_i - v_j]$, the second best is implemented by a mechanism that ensures a deal iff $\widetilde{U}_i^W - v_i + \widetilde{U}_j^W - v_j \leq \frac{3}{4}\left(S^p - v_i - v_j\right)$. Theorem 1 in our paper shows that the Nash bargaining protocol specified in our setup precisely ensure a deal under this condition.

Note that there are two differences between our bargaining setup with the recast Myerson and Satterthwaite's (1983) buyer-seller problem: First, in our model $\left\{\widetilde{U}_i^W, \widetilde{U}_j^W\right\}$ take their values from a uniformly distributed right triangle, with both side lengths equal to $S^p - v_i - v_j$; Second, we have the second stage of the game that grants each player the veto power. Suppose, by contradiction, that there exists an alternative Nash Bargaining protocol that delivers higher expected total gain from bargaining in our model setup, which features a subset of the square support and more stringent restrictions, this means that one can adopt this alternative protocol in the triangle support, and improve upon the M&S second best mechanism. This constitutes a contradiction.

D. Trade

In this section, we derive equations (5) and (6) in Section 2.1. In the Armington-Long-Plosser model, the representative firm in state i makes optimal decisions on labor and intermediate inputs given the wage rate W_i and prices of intermediate inputs $\{\widehat{p}_{ij}\}_{j=1}^N$. In equilibrium, price of good j is the geometric average of prices of all inputs. Specifically,

$$p_i = W_i^{\alpha} \Pi_{j=1}^N \widehat{p}_{ij}^{g_{ij}} \tag{D.1}$$

$$= W_i^{\alpha} \Pi_{j=1}^N \left(\frac{p_j}{\widehat{\tau}_{ij}}\right)^{g_{ij}}. \tag{D.2}$$

In vector form, equilibrium prices can be expressed as

$$\log \mathbf{P} = \left(\boldsymbol{I} - \boldsymbol{G}\right)^{-1}\left(\boldsymbol{\alpha} \log \mathbf{W} - \mathbf{T}\right), \tag{D.3}$$

where $\mathbf{P} = [p_1, p_2, ..., p_N]$ and $\mathbf{W} = [W_1, W_2, ..., W_N]$ represent vectors of nominal prices and wages, and $\mathbf{T}$ represents supply disturbances originating from iceberg trade costs, with $\mathbf{T}_i = \sum_{j=1}^{N} g_{ij}\tau_{ij}$.

Equilibrium allocations in the Cobb-Douglas setup also yield

$$\frac{p_i y_i}{W_i \overline{L}_i} = \frac{1}{\alpha_i}. \tag{D.4}$$

$$\frac{\widehat{p}_{ij} x_{ij}}{W_i \overline{L}_i} = \frac{g_{ij}}{\alpha_i}. \tag{D.5}$$

Now we turn to the representative consumer's optimization problem. In equilibrium, optimal consumption decisions of the representative consumer in state i is characterized by

$$\frac{\widehat{p}_{ij} c_{ij}}{W_i \overline{L}_i} = \beta_{ij} \tag{D.6}$$

and

$$\widehat{P}_i C_i = W_i \overline{L}_i, \tag{D.7}$$

where $\widehat{P}_i$, the price of the composite consumption good, is given by

$$\widehat{P}_i = \Pi_{j=1}^{N} \left(\widehat{p}_{ij}\right)^{\beta_{ij}}. \tag{D.8}$$

After substituting equations (D.3) into equation (D.7), we can obtain equation (5), the expression for the logarithm of the final consumption good.

Four conditions are satisfied in equilibrium: (i) the representative agent in each state maximizes utility by choosing optimal consumption allocations, (ii) the representative firm in each state maximizes output by choosing the optimal amount of labor and intermediate inputs, (iii) labor in each state is in full employment, and (iv) all goods markets are in equilibrium and all trades are balanced. Specifically, for each state j we have

$$p_j y_j = \sum_{i=1}^{N} \widehat{p}_{ij} \left(c_{ij} + x_{ij}\right), \tag{D.9}$$

where the left hand side represents total value of produced goods, and the right hand side represents total revenues from selling the goods as final consumption goods and intermediate inputs, both for the home state and the rest of the world.

After we apply equations (D.4), (D.5) and (D.6) to equation (D.9) , we obtain equation (6), the equilibrium conditions that pins down relative wage ratios.

E. Additional Tables

	$\lvert D_{i,j} - D_{j,i} \rvert$	$\lvert D_{i,i} - D_{j,j} \rvert$	bi_open	multi_open	log(distw)	cont	peacehist	peacehist_4
Mean	0.018	0.2557	0.0066	0.2333	8.1907	0.1233	9.0352	8.6280
Std	0.0318	0.2124	0.0118	0.0977	1.0536	0.3288	19.7865	19.9685
Min	0	0	0	0.0204	5.0571	0	0	0
Max	0.3886	1.6459	0.1301	0.6744	9.7965	1	115	116

Notes: Variable bil_open is measured as the logarithm of one plus the simple average of bilateral import flows over each state's GDP, while mul_open as the logarithm of one plus the simple average of each state's imports from other third party states over its respective GDP. Variable logdistw denotes the logarithm of the distance measure from the CEPII database. The variables distbil and distmul are the interaction term of logdistw with bil_open and mul_open respectively. The variable cont is a dummy variable that is equal to 1 when the two states' territories are either separated by a land or river border, or by 400 miles of water or less with no third state in between. The variables peacehist (peacehist _4) denote years after conflicts at level 3 (4) and above.

Table E.1: Summary Statistics of Regressors

	Conflict	$D_{C,U}$	$D_{U,C}$	$\lvert D_{C,U} - D_{U,C} \rvert$
1965	4	0.0002	0.0015	0.0013
1966	4	0.0002	0.0015	0.0013
1967	4	0.0002	0.0013	0.0011
1968	4	0.0002	0.0014	0.0012
1969	4	0.0002	0.0011	0.0009
1970	4	0.0002	0.0011	0.0009
1971	4	0.0002	0.001	0.0008
1972	4	0.0002	0.0035	0.0033
1994	3	0.01	0.0403	0.0303
1995	3	0.0128	0.0389	0.026
1996	3	0.0136	0.0368	0.0232
1999	3	0.0174	0.0422	0.0249
2000	3	0.013	0.0248	0.0118
2001	4	0.0128	0.0261	0.0133
2002	3	0.0154	0.0253	0.0099
2009	3	0.0405	0.0253	0.0151
2011	3	0.0527	0.0257	0.0269
2013	3	0.0559	0.0238	0.0321
2014	3	0.0581	0.0229	0.0352

Table E.2: China-US Conflicts

Table E.3: Robustness Checks

	(1) Mid3	(2) Mid3	(3) Mid3	(4) Mid3	(5) Mid3
$\lvert D_{i,j,t-4} - D_{j,i,t-4}\rvert$	-11.20***				
	(-2.60)				
$\lvert D_{i,i,t-4} - D_{j,j,t-4}\rvert$	1.249*				
	(1.89)				
bil_open_lag4	-177.4	-189.7**	539.3**	-232.3**	-47.06*
	(-1.62)	(-2.17)	(2.31)	(-1.97)	(-1.86)
mul_open_lag4	-1.567	7.348	-52.69	8.440	8.403***
	(-0.09)	(0.50)	(-1.49)	(0.57)	(2.91)
histconf	4.650***	4.144***	-2.799***	4.265***	4.395***
	(9.26)	(8.47)	(-4.06)	(8.34)	(21.34)
peacehist	-0.123***	-0.115***	-0.00960	-0.121***	-0.122***
	(-7.12)	(-6.06)	(-0.65)	(-5.56)	(-10.22)
logdistw	0.0564	0.378		0.243	0.0539
	(0.13)	(0.86)		(0.57)	(0.45)
cont	1.680***	1.635***		1.606***	1.578***
	(3.88)	(4.53)		(3.81)	(8.17)
distbil	25.81*	27.23**	-67.92**	29.90**	5.630*
	(1.80)	(2.43)	(-2.20)	(1.97)	(1.74)
distmul	-0.0817	-1.535	5.612	-1.307	-1.607***
	(-0.04)	(-0.76)	(1.31)	(-0.67)	(-3.97)
CHN	-0.547	0.388		0.235	-0.226
	(-1.63)	(0.79)		(0.81)	(-0.70)
UN5	0.593	0.397	-1.526	0.486	0.944***
	(1.30)	(0.87)	(-0.99)	(1.05)	(5.26)
$\lvert D_{i,j,t-1} - D_{j,i,t-1}\rvert$		-7.935*	-15.33*		
		(-1.84)	(-1.88)		
$\lvert D_{i,i,t-1} - D_{j,j,t-1}\rvert$		1.502***	1.877		
		(2.63)	(1.62)		
UN_votes_diff_lag1		0.0945			
		(0.90)			
area_max		-1.10e-07**			
		(-2.12)			
polity_min		0.00134*			
		(1.91)			
cons	-7.537**	-9.165***		-8.631**	-6.852***
	(-2.06)	(-2.63)		(-2.42)	(-7.24)
N	16691	19031	1402	19811	344330
Pseudo R^2	0.4539	0.4324		0.4280	0.4575
Dyad FE	No	No	Yes	No	No
Time Dummies	No	No	Yes	No	No
States	WIOD	WIOD	WIOD	WIOD	All

Notes: z statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Additional Notes for Table E.3: The dependent variables for all the five columns is a dummy variable that equals 1 when the highest level of hostility is coded 3 and above. Column (1) shows regression results when we take 4 lags of the two network measures, instead of 2 lags in the benchmark case. Column (2) shows regression results with one period lag of network measures, but additional control variables, such as UN_votes_diff, which measures the difference of the two states in UN votes; area_max, which denotes the area of the state with a larger territory; and Polity_min, which denotes the lowest polity score of the two states. Here Polity is the score that indexes the degree of democracy in a particular state. Column (3) reports the regression results controlling for dyad fixed effects and year dummies. Columns (4) and (5) report regression results without the two network measures respectively for our sample of WIOD states and all countries and regions including non-WIOD states. We use logit model regression for all regressions in the table.

F. Proofs of Lemmas

Proof of Lemma 1

Part (1) follows directly from equation of pr_s. For part (2), first note that when $V \leq min\left(2, \frac{S^p}{U^W} - 2\right)$, then $\overline{V}_k \leq R$ for $k = i,\ j$. This implies that Case III of Theorem 1 applies and the probability of war is zero. Next, for $V \in \left[min\left(2, \frac{S^p}{U^W} - 2\right), V^{max}\right]$, pr_s is well defined. Therefore, differentiating with respect to V shows that pr_s is increasing in V. Lastly, when $V = V^{max} = 2\frac{S^P}{U^W} - 4 \leq 2$ we have that $\overline{V}_k = S^P$ for $k = i,\ j$. In this case, $S^P - R = \frac{1}{4}[S^P - (v_i + v_j)]$ yielding a probability of war equal to $\frac{7}{16}$.

■

Proof of Lemma 2

Part (1) follows by taking derivatives with respect to $\frac{S^P}{U_i^W}$ and $\frac{U_j^W}{U_i^W}$ in equation (25). For part (2), it is straightforward to show that $\frac{\partial pr_{ij}}{\partial V} > 0$ in the region that the probability of war is positive. The value of V that equates $\overline{V}_i$ and R is given by $\frac{2\left(S^P - S^W\right)}{3U_i^W - U_j^W}$. When less than 2, it is the minimum value of V for the probability of war to be positive. When $\frac{2\left(S^P - S^W\right)}{3U_i^W - U_j^W} > 2$, the expected war damages are so large than the probability of war is zero for any $V \leq 2$. Next, theorem 1 shows that in Case II, ($\overline{V}_j \leq R < \overline{V}_i$), the probability of war can also be written as the product of $\frac{U_i^W}{U_i^W - U_j^W}$. and the ratio of the area of an isosceles triangle with side length $\frac{3}{2}VU_i^W - \frac{3}{4}\left[S^P - (v_i + v_j)\right]$ over the area of an isosceles triangle with side length $\frac{3}{2}VU_i^W$. Given that, we would have the highest probability of war when $V = \min\left(\frac{2\left(S^P - S^W\right)}{2U_i^W - U_j^W}, 2\right)$. When $\frac{2\left(S^P - S^W\right)}{2U_i^W - U_j^W} \leq 2$, which is equivalent to $\frac{S^P}{U_i^W} \leq 3$, there exists a V less than 2 that equates $\overline{V}_i$ with S^P, and consequently the length of the horizontal segment of the shaded obtuse triangle, $\frac{3}{2}VU_i^W - \frac{3}{4}\left[S^P - (v_i + v_j)\right]$, is $\frac{1}{4}$ of $\frac{3}{2}VU_i^W$. As a result, the maximum probability of war in the case is $\frac{1}{16}\frac{U_i^W}{U_i^W - U_j^W}$ given U_i^W and U_j^W. Algebraic manipulations show that the highest $\frac{U_i^W}{U_i^W - U_j^W}$ under the condition $\overline{V}_j \leq R < \overline{V}_i$ is 4, thus the highest probability of war when $\overline{V}_j \leq R < \overline{V}_i$ is $\frac{1}{4}$. Lastly, part (3) follows directly from equation (25)

■