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Complex global value chains and economic interdependence: a new look at the opportunity costs argument

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ABSTRACT

Under what conditions does economic interdependence increase or decrease state security? This article contributes to the scholarly debate on economic interdependence by examining the role of complex global value chains (GVCs) in deterring militarized conflict. It argues that GVC trade should be a far stronger deterrent to escalating conflict than other forms of trade, due to the importance of upstream inputs of strategic goods, which cannot be appropriated after conquest. Thus, the global fragmentation of production can have unintended positive spillovers for global peace. The article tests the importance of GVCs as opposed to regular trade flows for global peace by providing a qualitative comparative analysis (QCA) of all international crisis moments and their escalation. The causal mechanism is further illustrated with a qualitative case study of the global semiconductor supply chain and its role in relations between Taipei, Beijing, and Washington. Our theory and empirics suggest that GVCs on the whole are pacifying and that reshoring can have unintentional negative consequences for global peace.


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Introduction

The optimism about international relations (IR) that typified the post-Cold War era can be said to be well and truly over. Between the war in Ukraine and rising tensions between the United States (US) and China (PRC) over

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Taiwan, it is clear that the unipolar moment has passed. Great power competition is back with a vengeance. Despite the acknowledgment that today's world is more dangerous than yesterday's, international security theorists are divided on the question of just how likely great power conflict between China and the US really is. Neorealists are generally pessimistic, given the changes in the balance of power. Various strands of neorealist theory would predict either that the US—the established hegemon—would launch a war against the PRC—the rising power—(Allison, 2017; Copeland, 1996b), or that the rising power will challenge the hegemon in order to establish regional hegemony (Mearsheimer, 2014). By contrast, liberal scholars, particularly those working in the economic interdependence paradigm, are more skeptical about the imminence of great power conflict (Nye, 2020; Weede, 2010).

Within this scenario, we take note of and critically engage the following empirical puzzle. Despite China's disproportionate power vis-à-vis Taiwan, its ambition to capture what it views as a breakaway province, its military posturing in the region, and its various threats over the years of reunifying by force, Beijing has thus far made no obvious attempts to escalate the conflict into a military invasion. While some would point to the role of the US vouching to protect Taiwan, we note that the problem of projecting US military power across the Pacific Ocean decidedly gives the advantage to Beijing, especially given the island's limited geographic size and proximity to the PRC's shores. Instead, we argue that it is the unique economic relation between China and Taiwan, and how this relationship figures into the global economy through global value chains (GVCs), which has maintained the peace thus far.

A key academic debate in this context has been whether international linkages in trade and investment—interdependence—promote peace, or conflict. On the one hand, those working in the traditional, liberal 'opportunity costs' paradigm have emphasized that initiating conflict carries ever greater costs as levels of cross-border trade and investment rise (Brooks, 1999, 2005; Gartzke, 2007; Maoz, 2009; Nye, 2020; Weede, 2010). On the other hand, some scholars have argued that trade itself is endogenous to sharpened geopolitical tensions (Long, 2008), and that states concerned about losing trade in the future may escalate conflict before being put at too great a disadvantage vis-à-vis their adversary (Copeland, 1996a, 2015; Forland, 1991). Given high levels of trade and investment between the PRC and US, which perspective applies under which conditions is of crucial importance for accurately forecasting the likelihood of conflict between these two superpowers.

Previous contributions are inconclusive on whether trade leads to peace. On the one hand, scholars have argued that trade does induce peaceful cooperation as it increases the cost of war, albeit through

different mechanisms (Gartzke et al., 2001; Gowa & Mansfield, 1993; Oneal & Russett, 1997; Polachek, 1980; Reed, 2003). On the other hand, some studies found that trade does not always lead to peaceful cooperation, and in some cases even increases the likelihood of conflict (Barbieri, 1996, 2002; Gelpi & Grieco, 2008; Li & Reuveny, 2009; Morelli & Sonno, 2017; Peterson & Zeng, 2021; Spaniel & Malone, 2019; Tanaka et al., 2017; Zeng, 2024). While these works are foundational to the understanding of the trade-conflict nexus, they miss important parts of the picture. First, they only capture bilateral trade, thus missing how potential shifts in the security environment when a third strategically important state is present (cf. Chen, 2021). Our theoretical framework incorporates multilateral relationships.

Second, we introduce firms to our theory. Because previous studies mainly use aggregated trade in their empirics, they can neither say much about firms nor fully capture the sophistication of modern economic interdependence under the fragmentation of global production. Most international economic interactions today occur within GVCs, referring to a series of differentiated production stages of a good or service, with each stage adding value, and with at least two different countries involved in two stages (Antràs, 2015, 2020; Gereffi et al., 2005; Gereffi & Fernandez-Stark, 2016). Such ‘granularization’ of trade and production puts firms at the heart of the global economy and leads to a new pattern of economic interdependence. According to estimates of the United Nations (UN), international production networks account for no less than 80% of global trade, and ‘some 28% of gross exports consist of value added that is first imported by countries only to be incorporated in products or services that are then exported again’ (UNCTAD, 2013, p. ii). More recent estimates suggest that nearly half of all global trade is some form of GVC trade (World Bank, 2020), further emphasizing the importance of engaging with this topic for scholars using trade and global economic integration as an explanatory variable.

Examining the economic drivers of militarized conflict, we thus expect firms to have a strong influence on shaping states’ motivations to engage in conflict like they have on trade policies, as shown in the international political economy (IPE) literature (Johns & Wellhausen, 2016; Kim, 2017; Osgood, 2017, 2018). Because firms are profit-maximizers, they have a strong incentive to demand governments to provide policies that alleviate potential costs, including facilitating cross-border trade flows and minimizing conflict (Brook, 2005). Indeed, scholarship on the ‘military-industrial complex’ has examined the influence this interest group has on security and industrial policy (Adams, 1968; Koistinen, 2012; Snyder, 1991), but it focuses on how the military-industrial nexus causes war. Our theory

advances the literature of political economy of security by looking at how firms' interests can map onto states' strategic calculation of initiating large scale military action in the presence of GVCs. While trade fragmentation could be a strategy for firms to escape regulation and exploit workers (Cox, 2019), we show that an unintended, second-order consequence of GVCs is their pacifying effect on interstate relations.

In line with more recent work that has shown that the effect of interdependence on conflict is conditional (Dorussen, 2006; Gelpi & Grieco, 2008; Morelli & Sonno, 2017; Peterson & Zeng, 2021; Spaniel & Malone, 2019; Tanaka et al., 2017; Zeng, 2024), we develop a theory that incorporates the logic of GVCs into the opportunity costs of war argument. Despite accounting for an ever-greater part of global trade, previous contributions have overlooked the role of GVC trade for deterring conflict. We show that GVCs lower the probability of conflict by providing a strategically manipulable reliance on certain key intermediate goods. Secondly, we argue that this deterrent effect is strongest if there is also a 'bottleneck' in production: It is not just the scarcity of traded goods that matters for the deterrent effect of interdependence, but also the scarcity of upstream inputs of said traded goods. If anything, such linkages should be more deterrent than scarcity in bilateral trade, because scarcity in bilateral trade gives an incentive to initiate war to capture strategic resources (Forland, 1991), whereas the scarcity of intermediate inputs cannot be overcome by territorial occupation alone.

Following this logic, the pacifying effects of trade do not always take place, and conflicts and tensions can still happen when substantial trade flows exist. This is supported by the work of Davis and Meunier (2011), showing that aggregate economic flows in some sectors are not always affected by political tensions. Our findings reinforce their results by pointing out the conditions under which economic ties do or do not prevent states from militarized conflict. The costlier trade disruptions, the lower the probability of conflict. While our findings do not contradict those of Davis and Meunier (2011), they do suggest that certain conditions are more permissive of their argument, and others less. Moreover, by differentiating between GVC and non-GVC trade and looking at sectoral dynamics, we extend their findings with more empirical evidence on the conditions under which economic interdependence decreases conflicts.

We evaluate our theoretical predictions with a qualitative comparative analysis (QCA) of all relevant dyads between 1991 and 2014. We find that those dyads with high levels of GVC-trade are less likely to escalate to war than are dyads with less GVC trade. This provides support for our theoretical contribution: GVC trade could function as a pacifying factor. We further illustrate the causal logic of our theory by zooming in on contemporary relations between China, Taiwan, and various other

countries that are a part of the global semiconductor supply chain. We provide an account of continued peaceful relations between these states despite their geopolitical tension by focusing on the ability of suppliers to leverage their upstream GVC participation against conflict-initiating parties.

These insights are increasingly important for global politics in the modern era. While the world is more interconnected than ever in economic terms, recent threats to the global trade regime have caused some commentators to adopt the term ‘friendshoring’: the process by which production is relocated to states that have better relations with a firm’s country of origin (Maihold, 2022). Furthermore, as has been noted since the COVID-19 pandemic and the onset of the 2022 Russian invasion of Ukraine, GVCs are vulnerable due to the existence of bottlenecks in production: necessary steps in the value chain for which no or very few alternatives exist (Carvalho et al., 2020; Farrell & Newman, 2022; Orhan, 2022), giving further incentives to states to bring production home. If these commentators are correct, and the world is indeed becoming less interdependent and globalized, it could have quite disastrous consequences when combined with the rise of a new great power, as realists have argued (Copeland, 1996b). The policy implications of our arguments are subsequently profound: While international economic integration and bottlenecks in global production can be leveraged by states for their self-interest (Chen & Evers, 2023; Farrell & Newman, 2019, 2022), they may also be a potential force for peace by making conflict prohibitively expensive for potential belligerents. In the remainder of this article, we lay out how our theory departs from existing work on economic interdependence to make a novel contribution to the literature and illustrate the logic using QCA and an in-depth case study of the semiconductor industry.

A theory of GVCs and opportunity costs

The classical conception of the opportunity costs argument to interdependence and conflict goes as follows. Conflicts are started with the goal of achieving certain gains, be they security (as generally argued by realists), wealth (in neo-Marxist theory), or some intangible factor like status. However, there are also opportunity costs to war: These are the beneficial effects of peace that states forego when they engage in conflict. Among the most obvious of these beneficial effects are the economic efficiency gains arising from international economic liberalization (Keohane & Nye, 1973). When violence erupts, trade and investment fall, leading to increased opportunity costs for starting the conflict. While this would not make war fully absent—when the prospective gains from war outweigh the

prospective opportunity costs, war is still the ‘rational’ choice—it should decrease the probability of it occurring (Hegre et al., 2010; Maoz, 2009).

How do GVCs relate to this logic? We argue that more integrated and specialized global production will lead to costlier disruptions for the initiator of large-scale militarized conflict, deterring states from taking that action. The integrated nature of global production networks makes it more difficult for states, even the most powerful ones, to go to conflict with the hope of winning and fully seizing production processes from the ‘loser’, especially with prior global inputs, than it is to seize other types of production. When considering the role of firms, the logic of this argument is clearer. If a state engages in confrontation, not only would it risk its relations with other states within the GVCs, but also its international reputation with firms. Owning the inputs of production (capital, technologies, labor), firms are central in GVCs, and they would suffer from disruption, so they tend to avoid destinations that might have conflict. Consequently, even when a state proves victorious and successfully occupies the loser’s resources, it could trigger foreign firms’ withdrawal due to the potential cost of maintaining their business (Brooks, 1999, 2005). Upon losing these firms, the state is unable to get the necessary inputs or technologies to fully utilize the acquired resources. States might resort to ‘safer’ strategies such as economic coercion or threat of conflict, but this is not our focus. In this paper, we limit the scope to incidents that ultimately spiral into wars. This escalates the opportunity costs of violent conflict, in particular, when there are no alternative sources of a particular product (the ‘bottlenecks’ of global production) or when products with prior global inputs have strategic value (as we will show in our case studies). In this sense, what matters for states in deciding whether to initiate conflict is not simply how much they trade with their partners, but what they trade, which moves beyond the standard narrative of trade’s pacifying effects.

Our theory thus encompasses firms’ influence on the outbreak of war, albeit indirectly. GVC trade itself is largely structured and driven by investment and supplier decisions made by MNCs. Their cross-border investments and production decisions embed interdependence into the global economy, implying that states also suffer from firms’ potential losses following wars. In fact, both US and European industry groups—such as the Semiconductor Industry Association—have publicly lobbied against measures that heighten geopolitical tensions.¹ Thus, firms shape the strategic environment indirectly: By organizing GVCs and signaling economic risk, they influence state preferences. Contemporary globalization is characterized by transnational production systems that are increasingly integrated and coordinated through various market and non-market forms (Gereffi & Korzeniewicz, 1993). Previous insights have laid a

foundation for a GVC paradigm emphasizing the governance aspects of chains and their microfoundations, as well as organizational structure (Bair, 2005; Gereffi, 1996; Gereffi et al., 2005). A central insight is that GVCs arise from a mixture of coordination mechanisms within and across firms and states, and patterns of inter-firm control of the network could be analyzed *via* structural determinants such as transaction complexity, how information is codified, and supplier/buyer capabilities.

A similar theoretical contribution on the global fragmentation of production is the Global Production Network (GPN) approach. Coe and Yeung (2015, pp. 1-2) stated that the globalized economy consists of ‘organizationally fragmented and spatially dispersed production networks’, which is the key pillar for the emergence of global production networks coordinated by leading firms. In this sense, GPNs have theoretical overlap with GVCs, as both frameworks contend that production hinges on how firms, states, and other actors interact across time under shifting technologies and regulations. This framework also complements ours by shedding light on the ‘value capture’ processes that can result when a firm connects into a GPN (Coe & Yeung, 2019). Such a mechanism is key to our argument: The more value a state or firm can capture, the less substitutable it is, and the more geopolitical leverage it has. Building on the strands of scholarship discussed above, we seek to integrate the dynamics of GVCs into economic interdependence. Our theoretical argument, to some extent, overlaps with Blanchard and Ripsman (1996). Following their work, economic interdependence should be measured by the reliance of a state’s strategic goods, which are the critical ones to national defence and economic well-being. The key metrics to determine a state’s level of interdependence are the extent to which the supply of these goods is reduced in the event of conflict, and the extent to which states can secure such goods through the global economy. Our contribution focuses on how this logic plays out not only in bilateral relations, but also multilateral ones. As noted succinctly and eloquently by Dorussen (2006, p. 104) ‘not all trade is the same’. Considering the heterogeneity of traded goods and their potential strategic importance to states, our theory offers a more granular analysis compared to some previous works aggregating trade to a single explanatory variable of conflict outcome.

Another merit of incorporating GVCs in our theoretical framework is that they better capture patterns of contemporary economic interdependence. Economic interdependence can be either horizontal—bilateral transactions, or the flow of money and goods—or vertical—referring to the response of one economy to another in terms of changes in factor prices (Blanchard & Ripsman, 1996; Gasiorowski, 1985). Though aggregated trade can effectively measure the former dimension of economic interdependence, it does not tell us much about the latter. Not only does it reflect the

transaction flows between both states but also the response to factor prices changes. Because output is dependent on prior input, outputs—and therefore prices—are sensitive to upstream shocks in the value chain. Unlike previous contributions, which rely on the premise that conquerors can easily mobilize resources (Gilpin, 1981, 2016), we show that this is not always the case in the modern economy. With fragmentation and highly specialized global production, economic resources are no longer accumulable for expansionist states, as no single country, even the most powerful one, can control all production stages. Even when a state wins the war and successfully occupies a territory, the cost of doing so may well exceed the benefits of occupation. Modern economic resources include not only tangible (natural resources, production facilities, etc.) but also intangible factors (human capital, technology), which generate more value but are much more difficult to capture through conquest (Brooks, 2005).

Naturally, we are not the first to examine how today's globalized, interdependent economy has affected the probability of conflict. While we would never be able to do justice to the entire body of literature on this topic, we will briefly touch upon those contributions, which are most relevant for our own, and which allow us to illustrate the added value of this article for the field overall. Dorussen (2006) argued that the prospective ease of appropriating economic resources after conquest affects the opportunity costs of conflict, and that trade in products with more complex production processes should be more deterrent than trade in products that do not require advanced knowledge and technology, a point echoed by Van Evera (1991) in the context of Europe after the Cold War. Similarly, Brooks (1999, 2005) argued that 'the globalization of production has led to shifts in the structures of the most advanced states that would prevent a conqueror from effectively extracting economic gains from vanquished territory' (Brooks, 2005, p.161), because such behavior deters future foreign direct investment by MNCs. Li and Reuveny (2009) also disaggregated trade flows based on whether conflict will lower or raise the global price of the good (thus potentially offsetting decreased volumes of trade), and Zeng (2024) noted that some goods have security implications while others do not, and that the opportunity cost calculus will be different for both types.

What is missing in these articles is an appreciation of today's fragmented production processes and GVCs. Because of that, any particular product is not produced in one country. Rather, products rely on prior international inputs—imported, intermediary components necessary for the production of the final good—sometimes criss-crossing the globe several times before final assembly. Therefore, trade with prior global inputs is fundamentally different from other forms of trade, keeping constant explanations advocated by other scholars, and we explain why this matters

for the prospective gains from conflict below. Furthermore, this extension to the existing literature also allows us to speak to a broader class of conflicts: those that arise out of a need for strategic goods crucial to the survival of a state, rather than greed (Meierding, 2016; Zeng, 2024).

Specialization matters for states in GVCs, and this necessitates the disaggregation of trade into distinct types when examining the pacifying effect of economic interdependence. Globalization enmeshes states into a complex network of GVCs, making it hard to be autarkic. Some goods are more concentrated in certain producers and are strategically vital to national (economic or sovereign) security, hence making it harder to find alternatives on global markets (Blanchard & Ripsman, 1996; Li & Reuveny, 2009). If a state is highly specialized in producing these types of good or has close links with other specialized producers, it is less likely to be attacked by other powers since the cost of military mobilization combined with the high probability of being excluded from GVCs (accessing technology and strategic prior inputs) can far exceed the gains from occupation. In this regard, capitalist peace theory cannot capture the qualitative side of economic interdependence's pacifying effect (Gartzke, 2007), as it just looks at how much states trade with and invest in each other. Chen and Evers (2023), theorizing how the position of firms and their home states' economy affects business-state relations within a country over time, pointed out that the structure of global supply chains might encourage rather than discourage competition between great powers. They show that private interests and structural forces driving business-state relations play an important role in shaping conflict outcomes, but we go further by looking at the flow of prior trade inputs among the network and its influence on strategic interactions among countries.

Although situated squarely within the classical liberal logic of opportunity costs, our theory builds on and departs from these prior contributions. We argue that states are sensitive to the extent to which they could appropriate key strategic resources after invading (Dorussen, 2006; Frieden, 1994), and that they consider expected future changes in the foreign policies of other states (Copeland, 2015, 2024). On top of that, our work also builds on existing studies that acknowledge the role of alliance networks in extending the logic of interdependence from a bilateral situation, to a multilateral one (Chen, 2021; Dorussen, 1999; Fordham, 2010; Mansfield & Bronson, 1997). We place primary causal emphasis on the vertical interdependence effects of GVCs and their security implications. GVC bottlenecks tie together these insights from the literature and form the cornerstone of our original contribution.

Suppose we have a generic dyad with countries A and B. Country A trades some strategically important good with country B. Since the goods traded are of strategic importance to country B, and B is unable to

produce them itself, it has an incentive to invade and appropriate the production process of country A. This effect will be even stronger if B suspects A may stop exports (Chen & Evers, 2023; Zeng, 2024). Suppose now that a third country, creatively named C, is an ally of country A, and supplies A with some input, necessary to produce its strategic exports to B. Under this scenario, even if B were to successfully occupy A, it would not be able to benefit from the appropriation of the latter's production of the strategic good. In such a setup, it is most probable that country C would cease exports of machines necessary for the production of the good, thus negating the incentive B had to start the war with A in the first place. A graphical representation of this argument is provided in Figure 1. This leads us to our first hypothesis:

Hypothesis 1. *Conflict is less likely between countries that trade goods with prior inputs from global value chains.*

Note that this effect should be strongest if C is a bottleneck in the production of the strategic good. If C is the sole producer of these inputs (or has a near monopoly), then it will become nigh impossible for B to benefit from the appropriation of the industry in A. By contrast, if C is one of several existing producers of these machines, then the effect should be less pronounced. C can still decide to cease its exports to penalize B for its invasion of A. However, if other producers of the machines exist, and these other producers have no qualms to supply necessary prior inputs after the belligerence shown by B, then the result of such export controls will be a rise in the costs of the intermediary input. This may represent a total increase in the costs of acquiring the strategic good for B, such that the prospective gains in acquiring it are no longer sufficient to induce it toward escalating conflict with A. Nevertheless, the deterrent effect should logically be expected to be smaller than if C were a bottleneck in the GVC. Indeed, as argued by Hughes and Long (2015), the capability of states to use economic statecraft to coerce others depends not only on what market they aim to leverage, but also what their role in that market's supply chain is, and to what extent they monopolize this role. Therefore, countries that occupy a bottleneck in the GVC are better able to leverage their position and maintain peace (even if it is coerced) than are producers that do not occupy a bottleneck, as it would be much

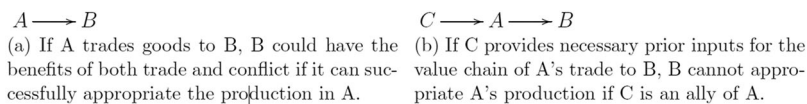


Figure 1. Trade and conflict with and without prior inputs.

more difficult to find alternative sources, which substantially increases the cost of disruption (Crescenzi, 2003; Peterson, 2014).

Hypothesis 2. *The pacifying effect of trade in goods with inputs from global value chains will be stronger if there is a bottleneck at an earlier stage of production.*

Our contribution advances other notions of the conditions under which invading states can reap economic gains through appropriation (Brooks, 1999, 2005; Dorussen, 2006; Forland, 1991). We note that such appropriation, even when feasible, may not yield the expected gains if production processes are made possible by prior global inputs from the value chain. While direct trade losses could be made up for by appropriation, disruption of GVCs cannot be so easily fixed, especially if there exist bottlenecks at upstream stages of the production process, and states controlling said bottlenecks are willing to leverage their unique position to punish belligerents. By disaggregating trade into distinct types based on international inputs, we contribute to the literature on weaponized interdependence. One of the key points made by Farrell and Newman (2019) is that the ability to capture chokepoints is critical to a state's coercive power. We contend that such chokepoints are also present in GVCs. States that occupy these can leverage that power. However, the relevant actors in Farrell and Newman (2019) are those states who weaponize their privileged position in the global economy; the relevant actors in our model are all states reacting to anticipated weaponized interdependence in their foreign policy making, and their position in the GVC will dictate their decision of initiating violent conflict.

Qualitative comparative analysis

We explore how GVC trade, referring to the value added of inputs that were imported to produce intermediate or final goods that are then exported to a third party, affects the likelihood of militarized conflict. Given the complex causal patterns linking our mechanisms to the outcome of interest, we combine an in-depth qualitative case study with qualitative comparative analysis (QCA), to avoid cherry-picking our cases. For our qualitative case study, we consider arguably the most important contemporary case of trade in strategic goods between international rivals: the PRC and Taiwan and its Western allies. Their geopolitical tensions and elevated level of interdependence in the semiconductor trade can strengthen our argument's internal validity. Semiconductors are a core component of many high-tech consumer and dual-use goods, and they are highly sophisticated and capital-intensive, as well as reliant on a globally fragmented production process, making this a good case for illustrating our theoretical mechanism.

By contrast, our QCA allows us to make inferences from a set of cases. Given the small number of militarized conflicts that we observe since 1991 (GVCs became prolific after the Cold War), doing a full quantitative analysis is not feasible for us to get meaningful results. QCA, relying on the logic of set theory, not only enables us to generalize our mechanisms through a reasonable number of cases but also to examine when different combinations or interactions of conditions lead to the presence or absence of the outcome of interest (Marx et al., 2014; Mello, 2022; Schneider & Wagemann, 2012). QCA thus provides us with more external validity, making our results less prone to either overgeneralization or myopic micro-investigations (Cederman & Vogt, 2017). A deeper discussion of QCA as a method for IR research is provided in the [online appendix](#). QCA can either be implemented as a crisp-set analysis, meaning all variables have exact binary cutoff points, or as a fuzzy-set, which is pseudo-continuous, ranging from 0 to 1 (Ragin, 2000). The values reflect the degree to which a case belongs to a given set: 1 indicates full membership, 0 indicates full non-membership, and 0.5 marks the point of maximum ambiguity. In the fuzzy-set framework, each variable is calibrated into set membership scores (0–1) using conceptually defined thresholds that translate continuous values into degrees of membership, indicating the extent to which each case belongs to the set in question. In order to acknowledge the nature of our data (trade flows are a continuous variable) and do justice to our theory (GVC trade flows that are larger should have a larger effect on states' propensity to escalate conflict), we implement a fuzzy-set analysis. In line with the best practice of QCA, we set the inclusion cutoff at 0.9, meaning that only configurations where at least 90% of cases sharing a condition pattern also exhibit the outcome are considered sufficient (Mello, 2022, p. 389). We provide more technical details on the thresholds and transformation of our calibration in section 3 of our online appendix. In QCA, researchers then implement a truth table, in which the various possible configurations of factors are provided, and configurations that poorly explain the outcome of interest are omitted. Lastly, Boolean minimization is employed to simplify the truth table's outcomes. For example, if the table indicates that factors A and B together, or factor A absent factor B both lead to the outcome of interest, then the logical conclusion is that factor A is a sufficient cause of the outcome, while B is unnecessary (Mello, 2022).

QCA helps us identify whether a particular factor or combinations of factors are enough on their own to produce an outcome (sufficiency), or whether some factors must always be present for the outcome to occur (necessity). The quantities that QCA generates to judge these values are inclusion and coverage. Inclusion refers to the share of observations with the outcome of interest that are explained by a given cause or combination of causes. Coverage refers to the number of cases that observe the outcome of interest

Table 1. Possible QCA outcomes.

	X=0	X=1
Y=1	a	c
Y=0	b	d

given the presence of a cause or observation of causes. To clarify using [Table 1](#), Inclusion would be calculated as $c/(a+c)$, and Coverage would be calculated as $c/(c+d)$, where X is an explanatory variable, and Y is the outcome.

In order to isolate the effect of GVCs, we focus on the post-1991 period in our empirical analysis. This has two reasons. First, the fragmentation of the global trade regime is a fairly recent development. By looking at the period after 1991, we ensure that all cases could potentially be exposed to high levels of GVC trade, thus giving us adequate variation in the main independent variable. Second, this approach allows us to ensure that our findings are relevant for the post-Cold War period, and that our findings are not driven by cases with low external validity for explaining contemporary conflict. In our QCA, we incorporate three variables. Besides our independent variable, which is total GVC trade (from WITS), we control for two other variables: conflict intensity (from MID), and whether the target state has an alliance with a Great Power (also from MID). The methodological literature on qualitative, variable-based research suggested that variables should be selected to rule out alternative theoretical explanations ([Gisselquist, 2014](#)). By controlling for conflict intensity and major power alliances, we account for explanations typically emphasized by the state-centric IR literature. Conflict intensity is defined as the most severe action observed in a dyad, ranging from 0 (no conflict) to 100 (interstate war). This measure captures a spectrum of behaviors, from threats and displays of force to limited and large-scale uses of force ([Goochman & Maoz, 1984](#); [Maoz, 1982](#), pp. 217–225). Accounting for conflict intensity is essential, as more severe initial incidents are more likely to escalate into war. Furthermore, prior research demonstrates that alliances—particularly those involving the US—exert significant deterrent effects on military conflict ([Bearce et al., 2006](#); [DiGiuseppe & Shea, 2021](#); [Leeds, 2003](#)). The outcome of interest is whether the dyad has militarized conflict within our timeframe.

For the period 1991–2014, we look at all cases that are covered by the MID data, which includes only ‘relevant dyads,’ i.e., dyads with an MID in given years. In total, this yields 286 cases with a directed dyad unit of analysis, as we distinguish between initiating and target states. Through our case selection, we account for such factors as distance and contiguity. Within this setup, we pool across the time series, which helps us minimize the problems associated with rare outcome events in studies of international

Table 2. Summary statistics QCA variables (raw).

Variable	N	Mean	Std. Dev.	Min.	Max.
Severity	286	61.392	18.513	20	100
GVC trade	286	2,702.009	12,273.820	0.017	145,949.800
US Alliance	286	0.238	0.426	0	1
No Conflict	286	0.944	0.230	0	1

conflict (King & Zeng, 2001). Our expectation is that the presence of GVC trade should be systematically related with fewer escalations.

QCA results

Our model explains the absence of interstate war. Our results are summarized in Table 2. The presence of GVCs is a strong predictor of peace: the inclusion score shows 98.3% of cases with high GVC trade do not observe conflict. This indicates that GVC integration is highly consistent as a sufficient path to the absence of war. The Proportional Reduction in Inconsistency (PRI) is also close to 1 across all conditions, meaning that they rarely occur together with war. The coverage of sufficiency (CovS) further supports this finding: High GVC trade alone explains 48.3% of peaceful cases. Furthermore, the unique coverage (CovU)—the share explained only by that factor—shows that GVCs account for an additional 19% of peaceful outcomes not captured by other variables. These numbers compare favorably to existing explanations in the literature. For example, the GVC variable performs nearly twice as well as whether the target state is a US ally in its Coverage. Interestingly, we find no interactive effects between our explanatory variables: Each is adequate in and of itself to explain the absence of conflict. More importantly, we also see that none of the three variables in our model is necessary to avoid war, including the presence of high levels of GVC trade.² GVCs, then, are not the only road to peace: Their existence is not necessary for peace, and other factors matter alongside this factor. Nevertheless, the existence of GVCs deters violence, albeit not as the sole deterministic factor. Militarized escalation of conflict is both random and costly (Gartzke, 1999), and what little predictive purchase we can get to explain that escalation is valuable in the grand scheme of things (Table 3).

Our QCA analysis provides several insights into the way in which GVC trade could affect the escalation of conflict. First, we find that the presence of GVCs is a strong predictor of the avoidance of war. Second, we find that, while GVCs are not the only causal pathway to avoid conflict, they do contribute to the absence of conflict. By and large, these results provide evidence for our assertion that GVC trade provides states a significant incentive to avoid war and conflict escalation. We reflect more on the implications of these findings in our ‘Discussion’ section. We

Table 3. QCA results (absence of war).

	Inclusion	PRI	CovS	CovU
GVCs = 1	0.983	0.983	0.483	0.189
Severity = 0	0.996	0.996	0.350	0.095
US Alliance = 1	0.971	0.971	0.244	0.090
Combined Conditions	0.982	0.982	0.699	

now turn to an in-depth case study of relations between China and Taiwan, and the role of the semiconductor industry to provide an illustration of our mechanism.

Qualitative case study

Some authors have presented evidence that suggests that conflict, or even the threat of conflict (Long, 2008), decreases aggregate trade and investment flows through the imposition of tariffs (Kim & Margalit, 2021), changes in consumer behavior (Pandya & Venkatesan, 2016; Weiss et al., 2023), and the launching of legal investigations into firms operating in geopolitical rivals (Tomashevskiy, 2021). Although Davis and Meunier (2011) showed that political tensions need not have a negative effect on trade, it is clear that they sometimes do. In other words, states faced with geopolitical or security pressures to initiate conflict can strategically limit their integration into GVCs prior to conflict onset, thus inducing a spurious negative correlation between GVC trade and the probability of militarized dispute initiation. To address these valid concerns and illustrate the causal logic of our theory, we consider arguably the most important contemporary case of trade in strategic goods between international rivals. The PRC's and Taiwan's and its Western allies' trade in semiconductor chips: a core component of high-tech consumer goods, but which can also be used for military purposes (Miller, 2022).

The focus on China and Taiwan for the illustration of our theoretical mechanism is based on both its contemporary relevance and its match with the QCA results of Table 3. As will be the focus of our subsequent paragraphs, both China and Taiwan are positioned in important parts of the GVC of semiconductors. Although it has traditionally operated under the implicit security umbrella of the US, Taiwan is not a formal military ally of the US. Furthermore, Beijing has strong domestic incentives to escalate its ongoing dispute with Taiwan over its *de facto* independence (Weiss & Wallace, 2021), thus indicating the severity of the situation for foreign policymakers. According to the QCA results, conflict can break out in the absence of GVCs, combined with a high degree of severity and a lack of a formal alliance. In the China-Taiwan case, there is no formal alliance, and China has a strong incentive to escalate owing to the

preferences of its public (Weiss & Wallace, 2021). The absence of conflict is therefore most likely explained by the presence of GVC trade.

China-Taiwan trade today

Semiconductors are widely recognized as one of the most important intermediary products in several global supply chains. Not only do they form the basis for many varieties of ‘smart’ consumer electronics, but they are also critical components of every technology that requires fast computing, including military computing. Several commentators have noted that future conflicts are going to be decided as much in cyberspace as in real space (Perlroth, 2021), and the capacity to have one’s programs run faster than those of their adversary will become more important as time progresses. Furthermore, even conventional arms make use of microprocessors for their guidance systems (Miller, 2022). Therefore, there is a strong security incentive for states to become self-sufficient in the production of high-grade semiconductors. However, due to the idiosyncrasy of the development of the computing industry in the second half of the twentieth century and the general business push for efficiency and specialization, the modern semiconductor GVC is dispersed across borders, and several parts of the chain are concentrated in specific countries (Miller, 2022). Multiple bottlenecks exist. The most important firms in this supply chain are located in China, Taiwan, Japan, South Korea, the Netherlands, and the US.

The most advanced semiconductors available in the world are produced by the Taiwan Semiconductor Manufacturing Company (TSMC). While TSMC is not primarily a designer of chips, nor in the business of producing software, it is the single most important ‘foundry’ of the semiconductor industry: It produces the majority of advanced chips for the global economy. While China would likely face harsh economic sanctions for invading Taiwan, appropriated TSMC production lines have the potential to replace China’s lost access to traded semiconductor chips in the case of armed conflict. As pointed out by Beaumier and Cartwright (2023), China is second in the world, just behind Taiwan, in production equipment imports, though it still trails other major players in terms of production capacity. Theoretically, if China could seize Taiwan, it would gain from access to the island’s top-notch production facilities, enabling it to catch up with the US in the geopolitical race for supremacy in the semiconductor industry.

However, the entire GVC of semiconductors and microchips is not captured within Taiwanese borders. It imports extreme ultraviolet (EUV) lithography machines in order to make its most advanced semiconductors, and these machines are exclusively produced in the Netherlands by the firm ASML. While previous generations of lithography

machines—so-called deep ultraviolet (DUV) lithography machines—are produced in other countries, most notably in Japan by Nikon, the latest generation of semiconductors can only be produced with the EUV variant of the technology. As a result, if China loses access to the most cutting edge EUV technology monopolized by ASML, it cannot operate the production facilities of TSMC, and risks its relations with the US and its allies as well as leading semiconductor firms like Samsung, Intel and Nikon, which are all based in the US or its allies. The Dutch government previously buckled to American pressure to prohibit exports of EUV machines to China (Alper et al., 2020). In early 2023, export controls were extended by both the Netherlands and Japan to the previous generation of DUV lithography machines (Leonard, 2023), and in 2025 the Dutch government even directly intervened in the operations of Chinese-owned chip-manufacturer Nexperia. Nominally, this was due to ‘mismanagement’ of the company, though ongoing tensions between China and the US and American pressure on the demissionary Dutch government likely played a role behind the scenes (Speelman, 2025). It seems plausible that a Chinese invasion of Taiwan would result in export restrictions to Taiwan as well. Indeed, as noted by Filkins (2022):

If China seized control of Taiwan’s semiconductor factories, it could conceivably force local workers to run them. But the factories depend on a constant flow of Western material, software, expertise, and engineers, without which production would cease in a matter of weeks. ... If the Chinese took the factories, there’s no way the West would help run them. ... It’s mutually assured destruction.

Without prior inputs of EUVs from the semiconductor supply chain, it would be impossible for Beijing to appropriate Taiwanese production, even setting aside the concerns of Dorussen (2006) about inducing compliance among laborers. Given the importance of these products for both the Chinese economy and its security strategy in an era of high-tech military technology, Beijing faces a formidable deterrent to its goals of bringing Taiwan under mainland control. Even if China would be able to start creating EUV lithography machines on its own, these machines themselves are dependent on extremely complex and specialized GVCs. For example, the lenses and mirrors that go into them need to be exceedingly smooth, and are produced by German firm Zeiss, which has a near monopoly on products of the appropriate level of quality. Fully ‘home-shoring’ the GVC of semiconductors would require not just appropriating or duplicating the fabrication processes of TSMC, but also those of ASML to guarantee access to EUVs. Even this feat would be insufficient, due to the constituent components of EUVs: software, lenses, laser tools and other advanced hardware (Miller, 2022, p. 234). Given the rarity of all of these intermediary components, it seems unlikely that any one

country—be it the US or PRC—would be able to fully internalize the supply chain of semiconductors. For its part, Beijing's near monopoly over rare earth elements and its manifested willingness to weaponize this resource (Seligman, 2022) mean that other states intimately involved in the semiconductor GVC have an incentive not to antagonize the PRC. Indeed, in 2023, China started to diminish its exports of gallium and germanium, both important materials used in the production of semiconductors, raising concerns about escalating economic tensions with Washington and the potential of further retaliatory measures (He, 2023).

These interdependencies are byproducts of a long history of state-firm strategic coordination. TSMC was established under Taiwan's state-led industrial strategy in the 1980s and still enjoys government subsidies (Miller, 2022). ASML, though fully private-owned, is sometimes considered to be the 'crown jewel' of the modern Dutch economy. Its links with the government are manifold, as it both exerts significant lobbying power,³ but is also being regulated more than other firms on account of the security implications of its products. Though it generally adheres to export-control regimes, it pushes back against the Dutch government when it feels the latter overreaches. Under the semiconductor value chain, such firms define the dynamics of the network, while states design and defend the regulatory frameworks that sustain them. In such a system, the economic and security stakes of disruption are mutually recognized, making the costs of conflict not only interstate but also systemic.

From this perspective, our theory and explanation generates predictions that run counter to those of Zeng (2024), who argued that the pacifying effects of bilateral trade will dissipate or even be reversed when the potential military gains from trade with a trade partner of similar size and power are smaller than the potential military gains from trade for the trade partner. Applied to the case of the semiconductor trade, the work of Zeng implies that this trade, having large security ramifications, could be potentially destabilizing because both the US and PRC are unwilling to provide the other party the necessary components that go into advanced weaponry, which may be used against them in the future. We view the work by Zeng as an important addition to the literature on the conditional importance of economic globalization for international conflict. However, we note that the importance of GVCs is underappreciated in this account. When countries occupy a choke point in the GVC, which they can only become by exporting products more efficiently than potential competitors, they gain a strategic resource for economic statecraft. Thus, states may have an incentive to export even strategically important goods to potential competitors if they can make said competitors reliant on their production.

In this sense, our perspective on the GVC of semiconductors runs closer to that of Beaumier and Cartwright (2023). We show that the

potential supply chain disruption caused by a military attack on Taiwan has a deterrent effect on China, thanks to Taiwan's connection with the Netherlands—the monopolizer of most advanced EUV technologies—and the US—the most dominant player in semiconductor chip design. Whereas their work provides a strong theoretical foundation for how states occupying chokepoints can leverage their power through weaponized interdependence, our contribution shows the effect this asymmetric interdependence has on other global players. In doing so, we broaden the field's understanding of weaponized interdependence.

None of this is to say that future militarized conflict between the PRC and Taiwan is impossible. Even absent changes in global economic affairs, it is important to note that Beijing's interest in Taipei is not purely economic or even strategic. There are strong domestic political incentives for China to remain involved in Taiwan as well (Weiss & Wallace, 2021). It is not unthinkable that domestic political pressures will force the CCP to become more assertive vis-à-vis Taipei in the future. Taiwan's pro-independence Democratic Progressive Party (DPP) claimed the Taiwanese Presidency in the 2024 election, extending its stay in power. While it is unclear whether new President Lai Ching-te (William Lai) will formally declare Taiwan to be a sovereign, independent nation, Beijing will surely feel as if the chances for peaceful reunification are dwindling. Domestic pressures may move Beijing to push harder for reunification, even if economic or security incentives would dictate otherwise. However, the economic rationale laid out in this paper does explain why the current mode of trade relations between the mainland and the island promote peace, rather than giving Beijing an incentive to try to appropriate the Taiwanese semiconductor industry.

Another possible reason to view our theory in a negative, rather than a positive light, would be the extent of 're-shoring' and industrial policy intended to de-globalize value chains in semiconductors, which both the PRC and US have engaged in. For Washington, this has mostly taken the form of providing tax incentives for TSMC to bring production of its most high-end chips to Arizona. For Beijing, it has included further investments in its own state-owned competitor to TSMC—Semiconductor Manufacturing International Corporation (SMIC)—as well as alleged corporate espionage of companies throughout the GVC, including ASML. Nevertheless, SMIC is not yet able to produce TSMC grade chips. China announced an embargo of Taiwan in the wake of Speaker Pelosi's August 2022 visit to Taiwan. While much bluster was involved in this episode, key goods, such as semiconductors, were notably omitted from it. Our theory implies that, when countries do not trade in products with prior GVC inputs, the probability of conflict rises. Thus, while current attempts at attaining self-sufficiency are sensible from the perspective of any

individual country, taken together they will increase the chance of conflict by lowering its opportunity costs.

The biggest danger of all would be when chokepoints cease to be chokepoints. Washington fears that Beijing will slowly chip away at all parts of the GVC over time, although the complexity of this value chain makes that scenario unlikely in our opinion. Indeed, the greater potential threat to peace comes from Sweden's recent discovery of the type of rare earth elements, which China previously had a near monopoly on, as well as attempts from the US to delve its domestic reserves of these metals (Seligman, 2022). Should the Swedish excavation prove to be capable of replacing Beijing's supply, and should Sweden fall more into the US sphere of influence as it seeks to join NATO, this may take away an important disincentive for Washington to escalate tensions with Beijing. Naturally, we have by now fallen into the realm of pure speculation and forecasting, and much remains uncertain about the future of relations between Washington, Beijing, and Taipei. As noted earlier, Beijing may initiate conflict despite strategic pressures to the contrary (Weiss & Wallace, 2021), and Washington may or may not fall for its Thucydides Trap. As all social scientific theories, ours is probabilistic, not determinative, a fact borne out by our QCA. Our account here should be read as such. However, we do believe that the complex GVC of semiconductors, at least right now, is a force for peace, rather than a source of conflict.

To tie the case study back to the results of our QCA analysis, we emphasize that the presence of GVCs is the only clearly present condition to avoid the escalation of conflict in the case of China-Taiwan relations. Taiwan has no official military alliance with the US, and, especially under the Trump administration, its commitment to the island's defence is uncertain.⁴ Furthermore, Beijing has strong domestic incentives to escalate its sovereignty dispute with Taipei: Reunification, even through military means, is highly popular among China's domestic audience (Weiss & Wallace, 2021). Thus, the case is characterized by both a strong incentive for the initiating power to escalate, and a lack of credible commitment to defend Taiwan militarily by the US. It is the presence of the one remaining factor identified by our QCA—GVC trade—that best explains the lack of military escalation in this context. Naturally, we are unable to state conclusively that this situation will persist indefinitely. The escalation of disputes into full-scale war is in part due to random factors that cannot be captured by variable-based modeling (Gartzke, 1999). Nevertheless, our case study highlights how GVC trade in particular might prove to be an inhibiting factor in the escalation of international conflict.

Discussion

Our findings shed light on an important emerging policy issue: how, why, and under which conditions GVCs matter for national security. As illustrated in our results, without interdependent GVCs, states more readily enter violent conflict, even when they trade with one another. We attribute this effect to the importance of prior inputs and how this problematizes the ease with which bellicose actors can appropriate key strategic and economic resources. Unlike traditional measures which primarily focus on the volume of trade, we argue that what goods and services exactly are traded, and the extent to which they rely on prior global inputs, matters in shaping patterns of interstate conflict. When a dyad has a large amount of total trade but a lack of prior inputs, conflict remains plausible. With the presence of GVC trade, especially non-substitutable upstream inputs, even small-scale conflicts can cause harm to both parties due to the criticality of disrupted sectors and the withdrawal of firms in these industries. Given the conditional effects of GVCs on mitigating violence, we consider it necessary to emphasize the centrality of maintaining resilient, differentiated networks of strategic goods production for both economic and national security. Even if individual states have a strategic incentive to decouple from GVCs (Clark et al., 2023; Maihold, 2022), doing so creates a situation where mutual decoupling makes the world overall less safe for everyone.

GVCs introduce an economic facet to conventional doctrines of national security, typically focused on military preponderance and border control. By being intertwined in these chains, countries add an economic buffer to their defence mechanisms, deterring potential adversaries by highlighting mutual economic losses in the event of conflict. As such, moving beyond traditional security alliances, our work implies that states in production or supply chain networks establish a form of benign (if sometimes asymmetrical) interdependence which can deter violent conflict. As a result, moves by the US to reshore and friendshore productions of key goods are quite questionable. With GVCs, any negative shock to one stage of production can propagate to the whole network, and the higher added-value a stage is, the higher the cost of disruption would be.

Moreover, Taiwan's centrality in high-end chip manufacturing currently imposes a built-in constraint on China's strategic calculus, as any invasion could trigger global backlash—not only politically, but economically—through supply disruptions. By friendshoring or reshoring, the US would erode this constraint, reducing the international stakes involved in a take-over of Taiwan. The act of decoupling, while framed as a hedge against conflict, may paradoxically diminish a powerful nonmilitary deterrent already in place. The implications of this argument for current relations between the US and China extend beyond this dyad. States embedded in

critical production networks—such as those centered on semiconductors—have strong incentives to maintain stable and cooperative relations. Sustaining these linkages is not only vital for national economic resilience, but also for preserving broader global economic stability and reducing the likelihood of conflict escalation across regions.

Notwithstanding its contributions, this paper has several limitations that future research should address. First, our QCA only runs up to 2014 due to data limitations, which limits our ability assess the temporal stability of the relationship between GVCs and conflict. Our findings are an important start, but hardly definitive. Second, our QCA is not fully causally identified in the design-based sense. Future research could address this issue by using more fine-grained data and alternative research designs. Third, our analysis is limited to full-scale militarized escalation. Contemporary conflict increasingly takes alternative forms, such as cyber attacks, coercion, and extrajudicial, extraterritorial missions, all of which are not captured by our chosen dependent variable. Our results speak only to the deterrent effects of GVC on one form of conflict, and we do not claim that the same logic necessarily extends to other behaviors. Lastly, although we provide qualitative, anecdotal evidence that firms matter for security outcomes due to their participation in GVCs, future work could leverage more granular firm-level data to establish microfoundations for the patterns we document.

Conclusion

The findings presented in this paper have significant ramifications for several recent developments in US-China relations and the geopolitics of global economic relations. Broadly speaking, the results presented in this paper suggest that so-called ‘re-shoring’ and ‘friend-shoring’—meant to make GVCs more resilient to political shock events by moving production back home or to committed allies (Clark et al., 2023; Maihold, 2022)—may have unintended negative effects for international security. If GVCs become fully included in the territory of allies, it takes away an important deterrent to the escalation of conflict. The exclusivity of certain goods can mitigate this for a while, as it forces one power to acquiesce to the interests of the power that holds exclusive access to such goods. However, in the long run, this strategy will fail. As soon as both powers have access to the same technologies and goods and have set up their supply chains at home or among allies, there will be no clear deterrent effect from trade as there are no GVC linkages between the belligerent groups. This is one potential explanation for why Washington has allowed its East Asian allies to continue operations within the PRC (Hayashi, 2023), even as it has made several moves to reshore its own strategic GVCs (Clark et al., 2023).

While semiconductor chips are the most obvious example of the theory discussed in this paper, it is certainly not the only case of supply chain bottlenecks in the global economy. Another example would be rare earth elements, which are necessary components of various forms of military technology, and have been used as a political bargaining chip several times over the past two decades (Seligman, 2022). Beijing's control of these resources levels the playing field in its competition with Washington to some extent, although the discovery of similar resources in Sweden—another US ally—will be cause for concern among the PRC's foreign policy intelligentsia, according to our theory.

More work undoubtedly remains to be done on this topic, possibly revivifying the economic interdependence debate after some stagnation. The paper's second hypothesis on bottlenecks in GVCs is hard to get at with quantitative data, the smallest aggregation of which is at the sectoral, rather than the product level. The qualitative component of the paper did speak to the bottleneck component of the theory by examining the role of EUV lithography machine exports from the Netherlands in deterring conflict between China and Taiwan. However, more rigorous quantitative tests are necessary to judge the external validity of this particular case. The study of global value and supply chains has slowly started to feature more prominently in the field of international relations and security (Chen, 2021; Chen & Evers, 2023; Dallas et al., 2019; Farrell & Newman, 2019; Zeng, 2024). This article has contributed to, but certainly not concluded, this emerging research agenda.

Notes

1. See: <https://www.semiconductors.org/wp-content/uploads/2024/07/SIA-Comments-on-Treasury-Outbound-ANPRM.pdf>. See also: <https://www.business-humanrights.org/en/latest-news/european-gas-lobby-groups-representing-total-shell-and-eni-reject-call-to-back-eu-plans-to-quit-russian-gas/>.
2. We conduct a necessity test to see whether a substantial presence of GVC trade is a necessary condition for peace, and the results show that it is not. We refer interested readers to [Appendix 4](#) for specific findings and discussions.
3. Former ASML CEO Peter Wennink was even commissioned by the Dutch government in late 2025 to put together an independent advisory rapport on which economic policies should be pursued in order to make the Dutch economy 'future-proof'.
4. We thank one of our anonymous reviewers for pointing this out to us.

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Data availability statement

For replication data, please contact Phuong Pham at ppham4@ur.rochester.edu

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