Supplementary Material for
The futility of economic sanctions in a globalized and interdependent world: a data-driven game theoretical study

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1 Details of quantitative trade models

We simulate the global trade flows between firms under short-term sanctions/retaliation based on the MRIO model [1, 2, 3]. The model works in a weekly time step. A firm is represented by the index pair ai, where a denotes the products produced by the firm and i denotes the region in which the firm is located. Each firm uses primary production factors (for simplicity, we only consider labor in the model) and domestic and foreign intermediate products to produce a specific product. We assume the labor input [denoted by $L_{ai}(t)$ for firm ai] will not change during the restriction period, i.e.,

$$L_{ai}(t) = L^*_{ai}, \tag{S1}$$

where L^*_{ai} is the labor input for firm ai before sanctions. Denote the set of intermediate products for firm ai as $\mathcal{I}_{ai}$. For intermediate product $b \in \mathcal{I}_{ai}$, the inventory that firm ai holds at the end of time $t-1$ and the amount arrived at firm ai from firm bj at time t are represented by $Inv^b_{ai}(t-1)$ and $PTF_{bj\to ai}(t)$, respectively. Then, the maximum output of firm ai at time t can be expressed by the following Leontief production function [4]:

$$x^{MAX}_{ai}(t) = \min\{\frac{L_{ai}(t)}{q^L_{ai}}; \{\frac{Inv^b_{ai}(t-1) + \sum_j PTF_{bj\to ai}(t)}{q^b_{ai}}\}_{b\in\mathcal{I}_{ai}}\}, \tag{S2}$$

where $q^L_{ai} = L^*_{ai}/x^*_{ai}$ and $q^b_{ai} = \sum_j Z^*_{bj\to ai}/x^*_{ai}$ are the input coefficients. Here, x^*_{ai} and $Z^*_{bj\to ai}$ are the output of firm ai and the trade flow from firm bj to firm ai before sanctions, respectively. The actual output of firm ai depends on its maximum output and its orders from clients, which is represented as

$$x^A_{ai}(t) = \min\left\{x^{MAX}_{ai}(t), \sum_j \left[OrdH_{j\to ai}(t-1) + \sum_b OrdF_{bj\to ai}(t-1)\right]\right\}. \tag{S3}$$

Here, $OrdH_{j\to ai}(t-1)$ is the orders issued by the household in country j to firm ai at time $t-1$; and $OrdF_{bj\to ai}(t-1)$ is the orders issued by firm bj to firm ai at time $t-1$. We assume that the output of firm ai is allocated proportionately to its clients by their orders, and the transit time is 1. Therefore, the amount of product a arrived at firm $b'j'$ from firm ai at time $t+1$ is

$$PTF_{ai\to b'j'}(t+1) = \frac{OrdF_{b'j'\to ai}(t-1)}{\sum_j \left[OrdH_{j\to ai}(t-1) + \sum_b OrdF_{bj\to ai}(t-1)\right]} x^A_{ai}(t). \tag{S4}$$

The amount of product a arrived at the household in country j' from firm ai is

$$PTH_{ai\to j'}(t) = \frac{OrdH_{j'\to ai}(t-1)}{\sum_j \left[OrdH_{j\to ai}(t-1) + \sum_b OrdF_{bj\to ai}(t-1)\right]} x^A_{ai}(t). \tag{S5}$$

The inventory of intermediate product b that firm ai holds at the end of time t is

$$Inv^b_{ai}(t) = Inv^b_{ai}(t-1) + \sum_j PTF_{bj\to ai}(t) - x^A_{ai}(t)q^b_{ai}. \tag{S6}$$

We assume that the target inventory of intermediate product b for firm ai at time t [denoted by $TarInv_{ai}^{b}(t)$] equals certain time steps (denoted by n_{ai}) of intermediate consumption of product b based on the latest production level, i.e.,

$$TarInv_{ai}^{b}(t) = n_{ai} q_{ai}^{b} x_{ai}^{A}(t). \tag{S7}$$

Therefore, the demand of intermediate product b for firm ai at time t is

$$DemF_{ai}^{b}(t) = \max\{TarInv_{ai}^{b}(t) - Inv_{ai}^{p}(t), 0\}. \tag{S8}$$

We assume that each firm issues orders from its suppliers to meet the demand for the intermediate products based on the suppliers' latest production level and import restrictions. The order issued by firm ai to firm bj at time t is

$$OrdF_{ai\to bj}(t) = \frac{Z_{bj\to ai}^{*} x_{bj}^{A}(t) Res_{bj\to i}(t)}{\sum_{j'} Z_{bj'}^{*} x_{bj'}^{A}(t) Res_{bj'\to i}(t)} DemF_{ai}^{b}(t). \tag{S9}$$

$Res_{bj\to i}(t) = 0$ if country i restricts imports of product b from country j at time t, otherwise, $Res_{bj\to i}(t) = 1$. We assume the final demand for all households will not change. Denote $DemH_{i}^{b^*} = \sum_j y_{bj\to i}^{*}$ is the demand of product b for the household in country i before sanctions; $y_{bj\to i}^{*}$ is the trade flow from firm bj to the household in country i before sanctions. Therefore, the order issued by the household in country i to firm bj at time t is

$$OrdH_{i\to bj}(t) = \frac{y_{bj\to i}^{*} x_{bj}^{A}(t) Res_{bj\to i}(t)}{\sum_{j'} y_{bj'\to i}^{*} x_{bj'}^{A}(t) Res_{bj'\to i}(t)} DemH_{i}^{b^*}. \tag{S10}$$

The total GDP change for firm ai at time t relative to the pre-sanction level is represented by

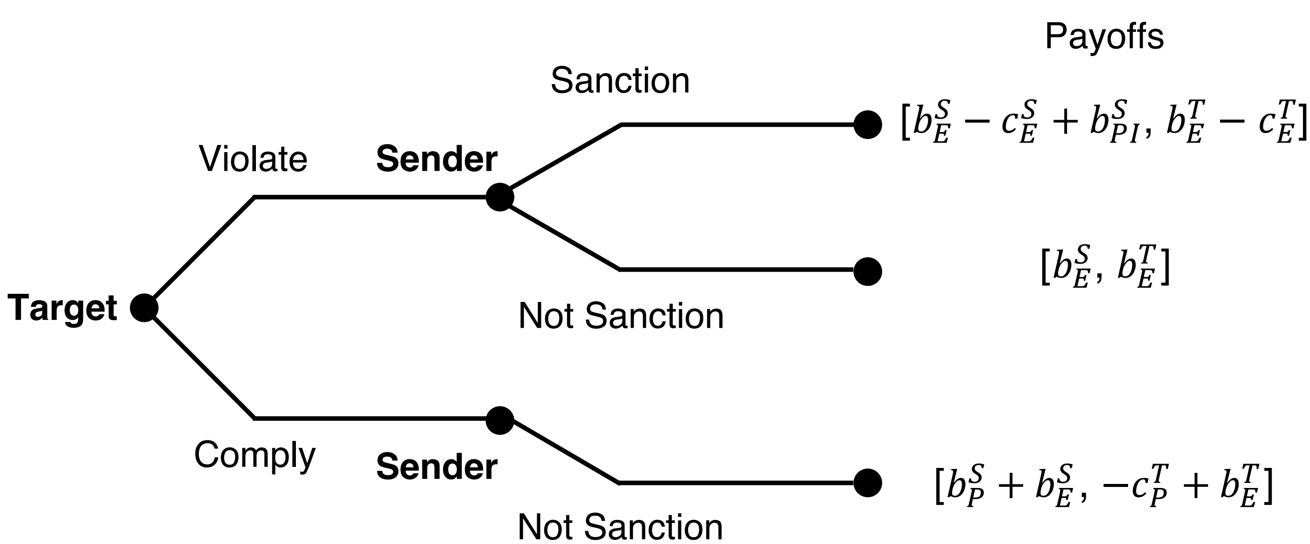
$$\Delta GDP_{ai}(t) = \frac{x_{ai}^{A}(t) q_{ai}^{L} - x_{ai}^{*} q_{ai}^{L}}{x_{ai}^{*} q_{ai}^{L}} = \frac{x_{ai}^{A}(t)}{x_{ai}^{*}} - 1. \tag{S11}$$

The GDP of a country is the sum of the GDP of all sectors (firms).

We characterize the long-term effects of decoupling using a general equilibrium model with input-output linkages [5, 6]. The barriers to trade between two countries in all intermediate products will be raised to infinity if one country decouples from another. Details of the equilibrium model can be found in [5].

2 Effectiveness of economic sanctions

The decision tree of the sanction game without the threat of retaliation is shown in Supplementary Fig. 1. The outcomes of the sanction game are shown in Supplementary Fig. 2.

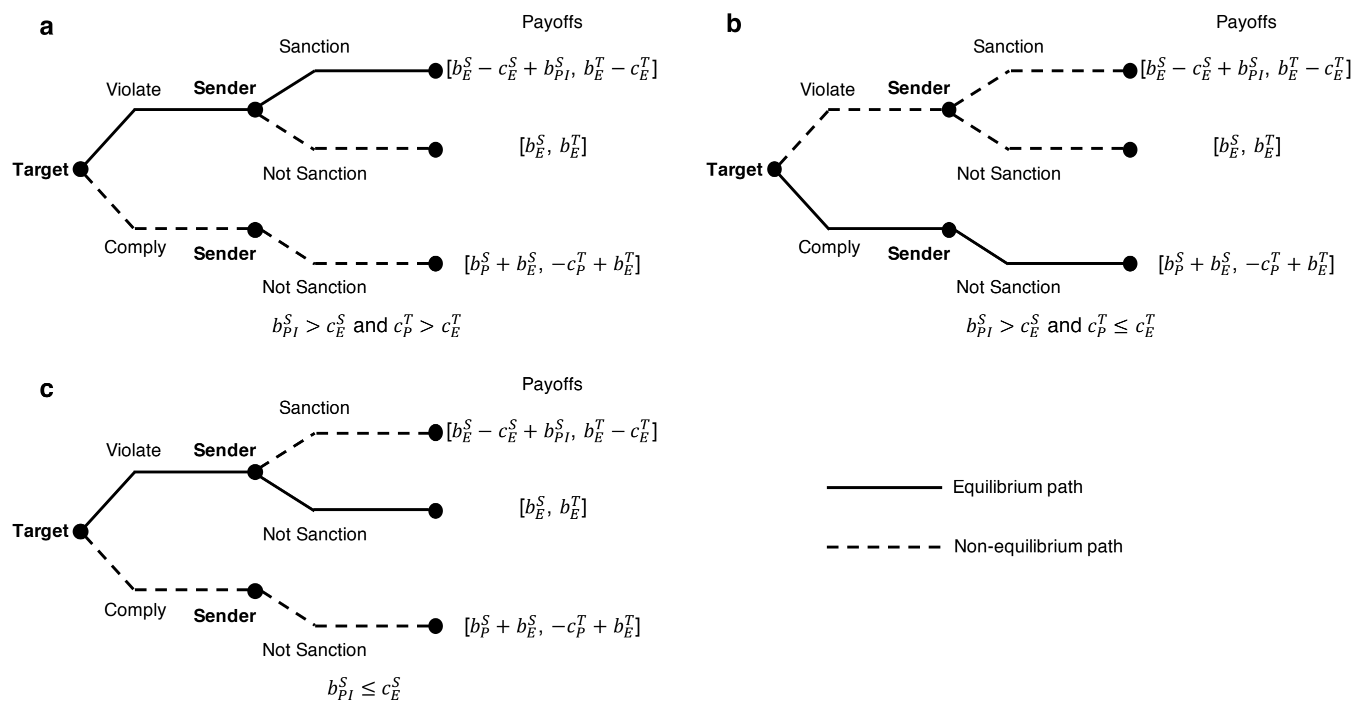


Supplementary Figure 1: The decision tree of the sanction game without the threat of retaliation.

Denote $\pi^S(\mathcal{G})$ and $\pi^T(\mathcal{G})$ as the pre-sanction GDP for the sender and the target, and $\pi^S(\mathcal{G} - g_{rT\to S})$ and $\pi^T(\mathcal{G} - g_{rT\to S})$ as the GDP for the sender and the target after sanctions, then, we define

$$b_E^S := \pi^S(\mathcal{G}), \tag{S12}$$
$$b_E^T := \pi^T(\mathcal{G}), \tag{S13}$$
$$c_E^S := \pi^S(\mathcal{G}) - \pi^S(\mathcal{G} - g_{rT\to S}) \tag{S14}$$
$$c_E^T := \pi^T(\mathcal{G}) - \pi^T(\mathcal{G} - g_{rT\to S}) \tag{S15}$$
$$b_P^S := \rho^S \pi^S(\mathcal{G}), \tag{S16}$$
$$c_P^T := \rho^T \pi^T(\mathcal{G}), \tag{S17}$$
$$b_{PI}^S := \xi^S \pi^S(\mathcal{G}). \tag{S18}$$

Here, ρ^S, ρ^T, and ξ^S are the ratios between political benefit/cost and the pre-sanction GDP.



Supplementary Figure 2: The outcomes of the sanction game without the threat of retaliation.

We assume that "comply-not sanction" is the optimal outcome for the sender, i.e., the sender can obtain the optimal payoff if she can achieve her political goals without resorting to punishment. Thus, $b_E^S + b_P^S > b_E^S - c_E^S + b_{PI}^S$, i.e.,

$$\rho^S \pi^S(\mathcal{G}) > -\pi^S(\mathcal{G}) + \pi^S(\mathcal{G} - g_{rT\to S}) + \xi^S \pi^S(\mathcal{G}) \tag{S19}$$
$$\rho^S > -1 + \frac{\pi^S(\mathcal{G} - g_{rT\to S})}{\pi^S(\mathcal{G})} + \xi^S \tag{S20}$$
$$\xi^S < \rho^S + \delta^S(\mathcal{G} - g_{rT\to S}), \tag{S21}$$

where

$$\delta^S(\mathcal{G} - g_{rT\to S}) = 1 - \frac{\pi^S(\mathcal{G} - g_{rT\to S})}{\pi^S(\mathcal{G})} \tag{S22}$$

is the reduction in GDP for the sender relative to pre-sanction levels. Similarly,

$$\delta^T(\mathcal{G} - g_{rT\to S}) = 1 - \frac{\pi^T(\mathcal{G} - g_{rT\to S})}{\pi^T(\mathcal{G})} \tag{S23}$$

is the reduction in GDP for the target relative to pre-sanction levels. Thus, we define

$$\xi^S = \frac{\rho^S + \delta^S(\mathcal{G} - g_{rT\to S})}{q^S}, \tag{S24}$$

where $q^S > 1$ is a constant value. The larger q^S is, the less political benefit the sender can obtain by maintaining a reputation for toughness. We set $q^S = 5$. Results based on other values can be found in the Supplementary Material.

Since the values of ρ^T, ρ^S, and ξ^S vary in different political goals, we define the effectiveness of trade sanctions imposed by the sender S on the product r from the target T (denoted by $\eta_{S,T,r}$) as the probability that sanctions success in supporting an arbitrary political goal. Economic sanctions are credited with success if the target complies, i.e., the "comply-not sanction" equilibrium is achieved ($b^S_{PI} > c^S_E$ and $c^T_P \leq c^T_E$; see Supplementary Fig. 2**b**). Therefore,

$$\eta_{S,T,r} = \mathcal{P}(b^S_{PI} > c^S_E, c^T_P \leq c^T_E | \delta^S(\mathcal{G} - g_{rT\to S}), \delta^T(\mathcal{G} - g_{rT\to S})). \tag{S25}$$

Here, $b^S_{PI} > c^S_E$ is equivalent to

$$\begin{aligned}
\xi^S \pi^S(\mathcal{G}) &> \pi^S(\mathcal{G}) - \pi^S(\mathcal{G} - g_{rT\to S}) \\
\frac{\rho^S + \delta^S(\mathcal{G} - g_{rT\to S})}{q^S} &> \delta^S(\mathcal{G} - g_{rT\to S}) \\
\rho^S &> (q^S - 1)\delta^S(\mathcal{G} - g_{rT\to S}).
\end{aligned} \tag{S26}$$

$c^T_P \leq c^T_E$ is equivalent to

$$\begin{aligned}
\rho^T \pi^T(\mathcal{G}) &\leq \pi^T(\mathcal{G}) - \pi^T(\mathcal{G} - g_{rT\to S}) \\
\rho^T &\leq \delta^T(\mathcal{G} - g_{rT\to S}).
\end{aligned} \tag{S27}$$

We assume that $\rho^S \in (0, l^S]$ and $\rho^T \in (0, l^T]$ are independent and follow uniform distribution. We set $l^S = l^T = 5\%$ based on the HSE dataset [7], one of the most widely used sanction datasets, which estimates the cost of sanctions for the target country as a percentage of national income. Then,

$$\begin{aligned}
\eta_{S,T,r} &= \mathcal{P}(b^S_{PI} > c^S_E, c^T_P \leq c^T_E | \delta^S(\mathcal{G} - g_{rT\to S}), \delta^T(\mathcal{G} - g_{rT\to S})) \\
&= \mathcal{P}(\rho^S > (q^S - 1)\delta^S(\mathcal{G} - g_{rT\to S}), \rho^T \leq \delta^T(\mathcal{G} - g_{rT\to S}) | \delta^S(\mathcal{G} - g_{rT\to S}), \delta^T(\mathcal{G} - g_{rT\to S})) \\
&= \mathcal{P}(\rho^S > (q^S - 1)\delta^S(\mathcal{G} - g_{rT\to S}) | \delta^S(\mathcal{G} - g_{rT\to S}))\mathcal{P}(\rho^T \leq \delta^T(\mathcal{G} - g_{rT\to S}) | \delta^T(\mathcal{G} - g_{rT\to S})) \\
&= \left[1 - \frac{\min\{(q^S - 1)\delta^S(\mathcal{G} - g_{rT\to S}), l^S\}}{l^S}\right] \frac{\min\{\delta^T(\mathcal{G} - g_{rT\to S}), l^T\}}{l^T}
\end{aligned} \tag{S28}$$

The expected payoff for the sender is

$$\begin{aligned}
\mathcal{E}^S_{S,T,r} =& \mathbb{E}\left[b^S_E - c^S_E + b^S_{PI} | b^S_{PI} > c^S_E, c^T_P > c^T_E\right] \Pr(b^S_{PI} > c^S_E, c^T_P > c^T_E) \\
&+ \mathbb{E}\left[b^S_E + b^S_P | b^S_{PI} > c^S_E, c^T_P \leq c^T_E\right] \Pr(b^S_{PI} > c^S_E, c^T_P \leq c^T_E) \mathbb{E}\left[b^S_E | b^S_{PI} \leq c^S_E\right] \Pr(b^S_{PI} \leq c^S_E) \\
&= \int_{\min\{(q^S-1)\delta^S(\mathcal{G}-g_{rT\to S}), l^S\}}^{l^S} \frac{b^S_E - c^S_E + b^S_{PI}}{l^S} d\rho^S \left[1 - \frac{\min\{\delta^T(\mathcal{G} - g_{rT\to S}), l^T\}}{l^T}\right] \\
&+ \int_{\min\{(q^S-1)\delta^S(\mathcal{G}-g_{rT\to S}), l^S\}}^{l^S} \frac{b^S_E + b^S_P}{l^S} d\rho^S \frac{\min\{\delta^T(\mathcal{G} - g_{rT\to S}), l^T\}}{l^T} \\
&+ \int_0^{\min\{(q^S-1)\delta^S(\mathcal{G}-g_{rT\to S}), l^S\}} \frac{b^S_E}{l^S} d\rho^S \\
&= \pi^S(\mathcal{G}) + \int_{\min\{(q^S-1)\delta^S(\mathcal{G}-g_{rT\to S}), l^S\}}^{l^S} \frac{-\pi^S(\mathcal{G}) + \pi^S(\mathcal{G} - g_{rT\to S}) + \xi^S \pi^S(\mathcal{G})}{l^S} d\rho^S \left[1 - \frac{\min\{\delta^T(\mathcal{G} - g_{rT\to S}), l^T\}}{l^T}\right] \\
&+ \int_{\min\{(q^S-1)\delta^S(\mathcal{G}-g_{rT\to S}), l^S\}}^{l^S} \frac{\rho^S \pi^S(\mathcal{G})}{l^S} d\rho^S \frac{\min\{\delta^T(\mathcal{G} - g_{rT\to S}), l^T\}}{l^T}
\end{aligned} \tag{S29}$$

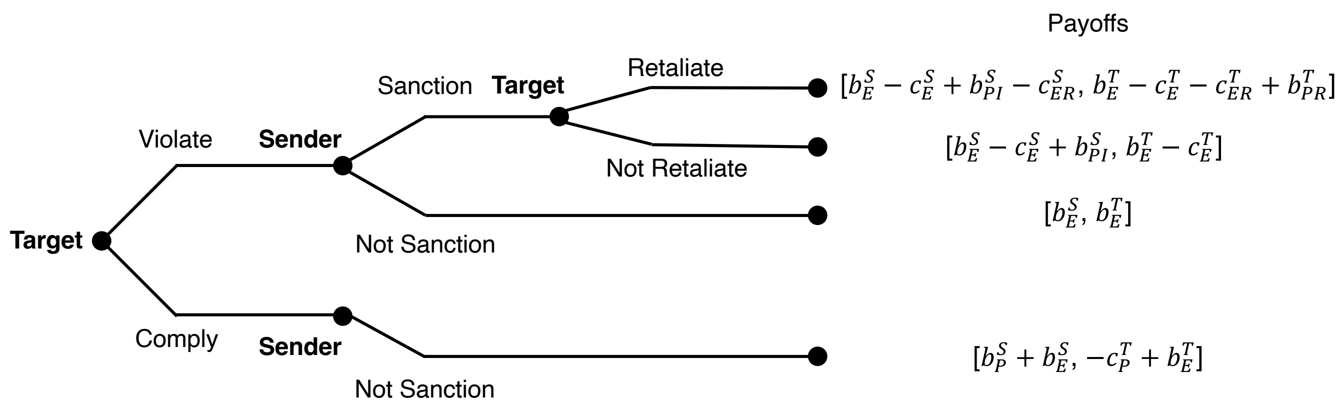
Denote $\theta^S = l^S - \min\{(q^S - 1)\delta^S(\mathcal{G} - g_{rT\to S}), l^S\}$ and $\theta^T = l^T - \min\{\delta^T(\mathcal{G} - g_{rT\to S}), l^T\}$, then, the expected payoff for the target is

$$\begin{aligned}
\mathcal{E}^T_{S,T,r} &= \frac{\theta^S}{l^S} \int_{l^T - \theta^T}^{l^T} \frac{b^T_E - c^T_E}{l^T} d\rho^T + \frac{\theta^S}{l^S} \int_0^{l^T - \theta^T} \frac{-c^T_P + b^T_E}{l^T} d\rho^T + (1 - \frac{\theta^S}{l^S}) \int_0^{l^T} \frac{b^T_E}{l^T} d\rho^T \\
&= \frac{\theta^S}{l^S l^T} \left[\int_{l^T - \theta^T}^{l^T} b^T_E - c^T_E d\rho^T + \int_0^{l^T - \theta^T} -c^T_P + b^T_E d\rho^T\right] + \frac{l^S - \theta^S}{l^S l^T} \int_0^{l^T} b^T_E d\rho^T
\end{aligned}$$

$$
\begin{aligned}
&= \frac{\theta^S}{l^S l^T}\left[\int_{l^T-\theta^T}^{l^T} b_E^T d\rho^T - \int_{l^T-\theta^T}^{l^T} c_E^T d\rho^T - \int_0^{l^T-\theta^T} c_P^T d\rho^T + \int_0^{l^T-\theta^T} b_E^T d\rho^T\right] + \frac{l^S-\theta^S}{l^S l^T}\int_0^{l^T} b_E^T d\rho^T \\
&= \frac{\theta^S}{l^S l^T}\left[\int_0^{l^T} b_E^T d\rho^T - \int_{l^T-\theta^T}^{l^T} c_E^T d\rho^T - \int_0^{l^T-\theta^T} c_P^T d\rho^T\right] + \frac{l^S-\theta^S}{l^S l^T}\int_0^{l^T} b_E^T d\rho^T \\
&= \frac{\theta^S}{l^S l^T}\int_0^{l^T} b_E^T d\rho^T + \frac{l^S-\theta^S}{l^S l^T}\int_0^{l^T} b_E^T d\rho^T - \frac{\theta^S}{l^S l^T}\left[\int_{l^T-\theta^T}^{l^T} c_E^T d\rho^T + \int_0^{l^T-\theta^T} c_P^T d\rho^T\right] \\
&= b_E^T - \frac{\theta^S}{l^S l^T}\left[\int_{l^T-\theta^T}^{l^T} c_E^T d\rho^T + \int_0^{l^T-\theta^T} c_P^T d\rho^T\right] \\
&= \pi^T(\mathcal{G}) - \frac{\theta^S}{l^S l^T}\left[\int_{l^T-\theta^T}^{l^T} \pi^T(\mathcal{G}) - \pi^T(\mathcal{G}-g_{rT\to S})d\rho^T + \int_0^{l^T-\theta^T} \rho^T\pi^T(\mathcal{G})d\rho^T\right] \\
&= \frac{\pi^T(\mathcal{G})}{l^S l^T}\left[l^S l^T - \theta^S(\int_{l^T-\theta^T}^{l^T} \delta^T(\mathcal{G}-g_{rT\to S})d\rho^T + \int_0^{l^T-\theta^T} \rho^T d\rho^T)\right] \\
&= \frac{\pi^T(\mathcal{G})}{l^S l^T}\left\{l^S l^T - \theta^S[\theta^T\delta^T(\mathcal{G}-g_{rT\to S}) + \frac{(l^T-\theta^T)^2}{2}]\right\}.
\end{aligned} \tag{S30}
$$

3 Effectiveness of economic sanctions under the threat of retaliation

The decision tree of the sanction game under the threat of retaliation is shown in Supplementary Fig. 3. If $b_{PR}^T \le c_{ER}^T$,



Supplementary Figure 3: The decision tree of the sanction game under the threat of retaliation.

the game becomes the original game as in Supplementary Fig. 1, otherwise, it becomes a new game in Supplementary Fig. 4**b**, of which the outcomes are shown in Supplementary Fig. 5.

We assume that "violate-not sanction" is the optimal outcome for the target, i.e.,

$$
\begin{aligned}
b_E^T &> b_E^T - c_E^T - c_{ER}^T + b_{PR}^T, \\
b_{PR}^T &< c_E^T + c_{ER}^T.
\end{aligned} \tag{S31}
$$

Thus, we define

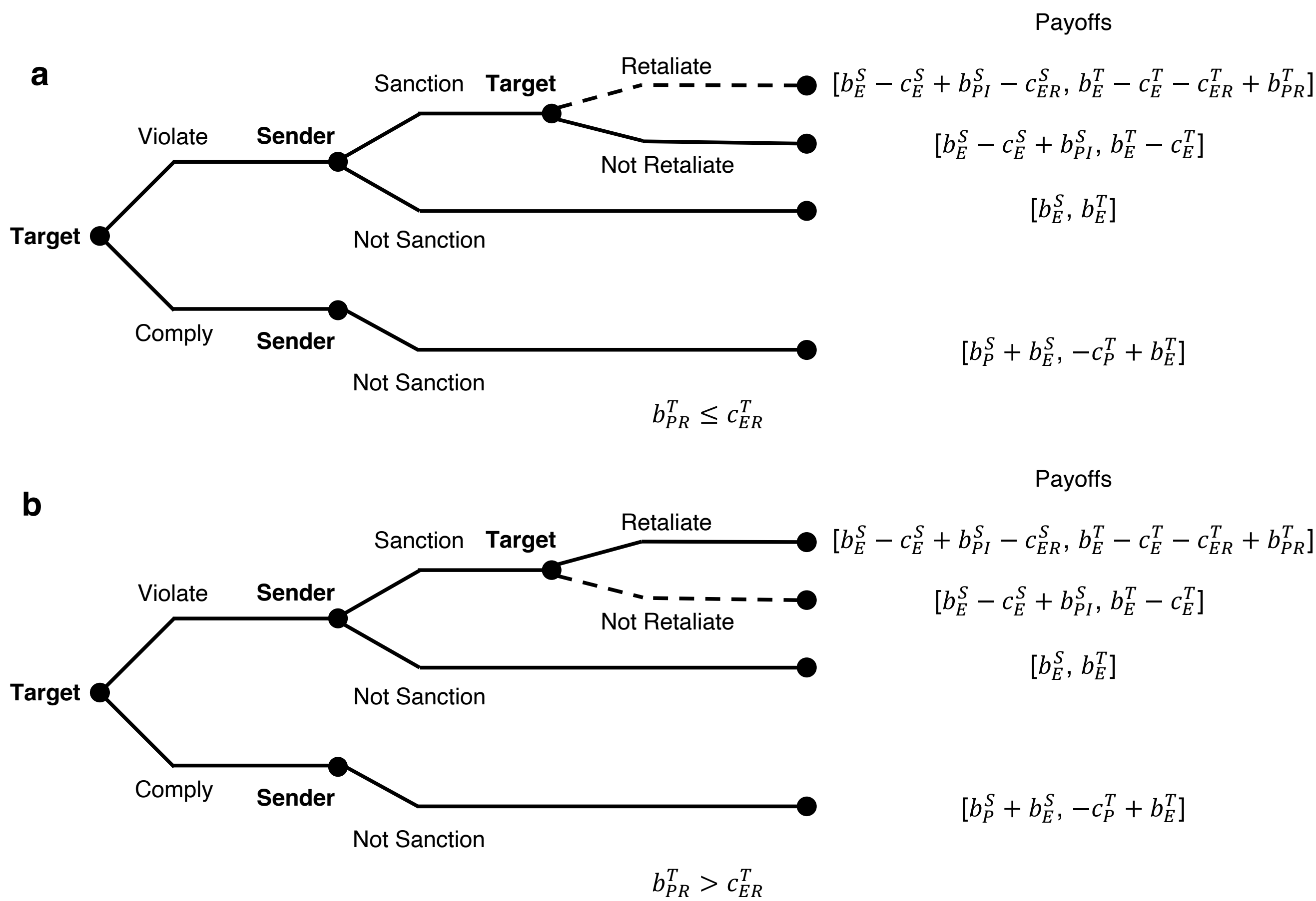
$$
b_{PR}^T = \frac{c_E^T + c_{ER}^T}{q^T}, \tag{S32}
$$

where $q^T > 1$ is a constant value. The larger q^T is, the less political benefit the target can obtain through retaliation. We set $q^T = 5$ in the main text. Results based on other values can be found in the Supplementary Material.

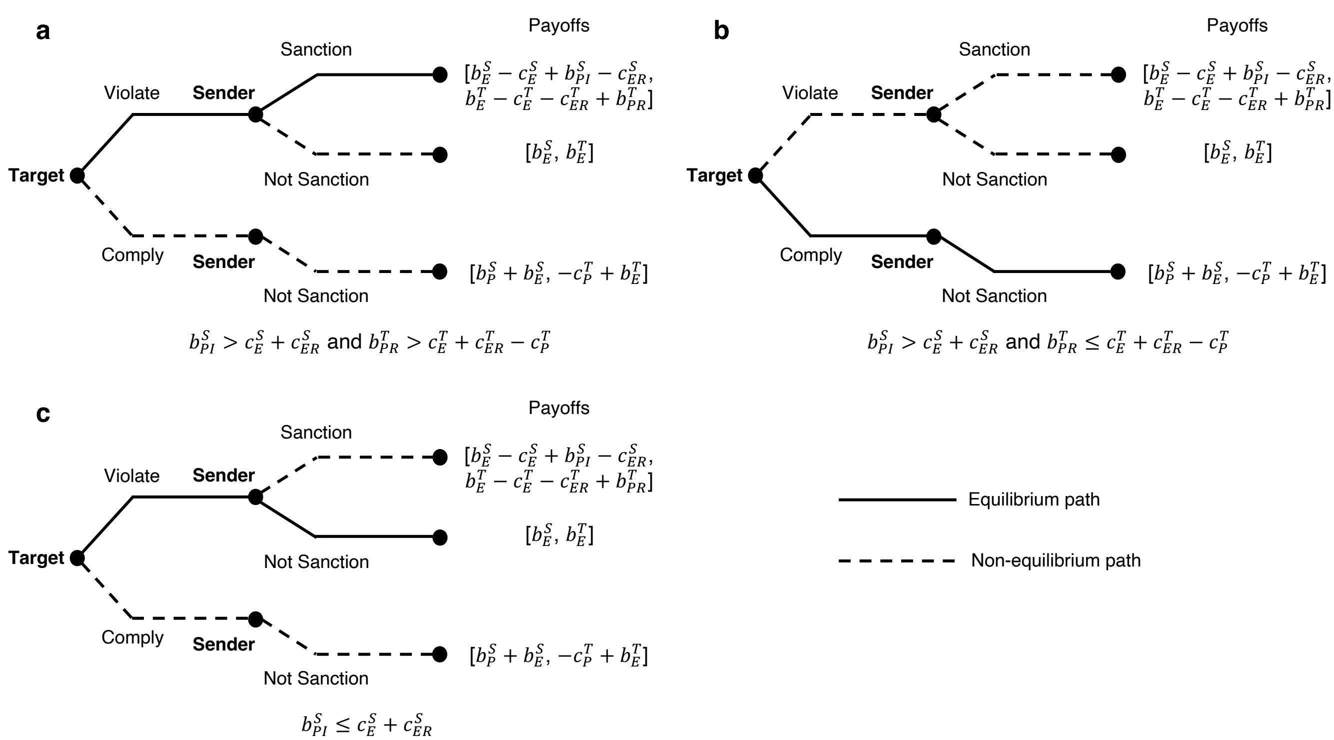
Denote the trade linkages deleted under retaliation strategies imposed by the target T against the sender S as $g_{S\to T}^R$. Then, we denote

$$
c_{ER}^S := \pi^S(\mathcal{G}-g_{rT\to S}) - \pi^S(\mathcal{G}-g_{rT\to S}-g_{S\to T}^R) = \pi^S(\mathcal{G})[\delta^S(\mathcal{G}-g_{rT\to S}-g_{S\to T}^R) - \delta^S(\mathcal{G}-g_{rT\to S})], \tag{S33}
$$

$$
c_{ER}^T := \pi^T(\mathcal{G}-g_{rT\to S}) - \pi^T(\mathcal{G}-g_{rT\to S}-g_{S\to T}^R) = \pi^T(\mathcal{G})[\delta^T(\mathcal{G}-g_{rT\to S}-g_{S\to T}^R) - \delta^T(\mathcal{G}-g_{rT\to S})] \tag{S34}
$$



Supplementary Figure 4: The decision tree of the subgames of the sanction game under the threat of retaliation.



Supplementary Figure 5: The outcomes of the subgames of the sanction game under the threat of retaliation when $b_{PR}^T > c_{ER}^T$.

$$b_{PR}^T = \frac{c_E^T + c_{ER}^T}{q^T} = \frac{\pi^T(\mathcal{G}) - \pi^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)}{q^T} = \frac{\pi^T(\mathcal{G})\delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)}{q^T}, \tag{S35}$$

where

$$\delta^S(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R) = 1 - \frac{\pi^S(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)}{\pi^S(\mathcal{G})},$$
$$\delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R) = 1 - \frac{\pi^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)}{\pi^T(\mathcal{G})}.$$

Then, the effectiveness of sanctions under the threat of retaliation is

$$\eta_{S,T,r}^R = \begin{cases} \eta_{S,T,r}^{re} & b_{PR}^T > c_{ER}^T, \\ \eta_{S,T,r} & b_{PR}^T \le c_{ER}^T, \end{cases} \tag{S36}$$

where

$$\begin{aligned} \eta_{S,T,r}^{re} = \mathcal{P}(& b_{PI}^S > c_E^S + c_{ER}^S, b_{PR}^T \le c_E^T + c_{ER}^T - c_P^T | \\ & \delta^S(\mathcal{G} - g_{rT\to S}), \delta^T(\mathcal{G} - g_{rT\to S}), \delta^S(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R), \delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)). \end{aligned} \tag{S37}$$

Here, $b_{PR}^T > c_{ER}^T$ is equivalent to

$$\begin{aligned} \frac{\pi^T(\mathcal{G})\delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)}{q^T} &> \pi^T(\mathcal{G})[\delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R) - \delta^T(\mathcal{G} - g_{rT\to S})], \\ \frac{\delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)}{q^T} &> \delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R) - \delta^T(\mathcal{G} - g_{rT\to S}), \\ \delta^T(\mathcal{G} - g_{rT\to S}) &> \delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)\frac{q^T - 1}{q^T}, \\ \delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R) &< \frac{q^T}{q^T - 1}\delta^T(\mathcal{G} - g_{rT\to S}). \end{aligned}$$

$b_{PI}^S > c_E^S + c_{ER}^S$ is equivalent to

$$\begin{aligned} \xi^S\pi^S(\mathcal{G}) &> \pi^S(\mathcal{G})\delta^S(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R), \\ \xi^S &> \delta^S(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R), \\ \frac{\rho^S + \delta^S(\mathcal{G} - g_{rT\to S})}{q^S} &> \delta^S(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R), \\ \rho^S &> q^S\delta^S(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R) - \delta^S(\mathcal{G} - g_{rT\to S}). \end{aligned}$$

$b_{PR}^T \le c_E^T + c_{ER}^T - c_P^T$ is equivalent to

$$\begin{aligned} \frac{\pi^T(\mathcal{G})\delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)}{q^T} &\le \pi^T(\mathcal{G})\delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R) - \rho^T\pi^T(\mathcal{G}), \\ \frac{\delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)}{q^T} &\le \delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R) - \rho^T, \\ \rho^T &\le \delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)\frac{q^T - 1}{q^T}. \end{aligned}$$

Then,

$$\begin{aligned} \eta_{S,T,r}^{re} = \mathcal{P}(& \rho^S > q^S\delta^S(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R) - \delta^S(\mathcal{G} - g_{rT\to S}), \\ & \rho^T \le \delta^T(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R)\frac{q^T - 1}{q^T} | \\ & \delta^S(\mathcal{G} - g_{rT\to S}), \delta^T(\mathcal{G} - g_{rT\to S}), \delta^S(\mathcal{G} - g_{rT\to S} - g_{S\to T}^R), \delta^T(\mathcal{G} - g_{rT\to S}) - g_{S\to T}^R), \end{aligned}$$

$$= \frac{1}{l^S l^T} \int_{\min\{q^S\delta^S(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})-\delta^S(\mathcal{G}-g_{rT\to S}),l^S\}}^{l^S} \int_0^{\min\{\delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})\frac{q^T-1}{q^T},l^T\}} d\rho^S d\rho^T,$$

$$= \left[1 - \frac{\min\{q^S\delta^S(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})-\delta^S(\mathcal{G}-g_{rT\to S}),l^S\}}{l^S}\right] \frac{\min\{\delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})\frac{q^T-1}{q^T},l^T\}}{l^T}. \quad (S38)$$

Denote

$$\theta^S_{re} = l^S - \min\{q^S\delta^S(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})-\delta^S(\mathcal{G}-g_{rT\to S}),l^S\},$$
$$\theta^T_{re} = l^T - \min\{\delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})\frac{q^T-1}{q^T},l^T\},$$

then, the expected payoff for the target when $\delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T}) < \frac{q^T}{q^T-1}\delta^T(\mathcal{G}-g_{rT\to S})$ is

$$\mathcal{E}^{T,re}_{S,T,r} = \frac{\theta^S_{re}}{l^S l^T}\left[\int_{l^T-\theta^T_{re}}^{l^T} b^T_E - c^T_E - c^T_{ER} + b^T_{PR} d\rho^T + \int_0^{l^T-\theta^T_{re}} b^T_E - c^T_P d\rho^T\right] + (1-\frac{\theta^S_{re}}{l^S})b^T_E,$$
$$= b^T_E + \frac{\theta^S_{re}}{l^S l^T}\left[\int_{l^T-\theta^T_{re}}^{l^T} -c^T_E - c^T_{ER} + b^T_{PR} d\rho^T + \int_0^{l^T-\theta^T_{re}} -c^T_P d\rho^T\right],$$
$$= \pi^T(\mathcal{G}) + \frac{\theta^S_{re}}{l^S l^T}\left[\int_{l^T-\theta^T_{re}}^{l^T} \frac{\pi^T(\mathcal{G})\delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})}{q^T} - \pi^T(\mathcal{G})\delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})d\rho^T - \int_0^{l^T-\theta^T_{re}} \rho^T\pi^T(\mathcal{G})d\rho^T\right],$$
$$= \pi^T(\mathcal{G})\left\{1 + \frac{\theta^S_{re}}{l^S l^T}\left[\int_{l^T-\theta^T_{re}}^{l^T} \frac{\delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})}{q^T} - \delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})d\rho^T - \int_0^{l^T-\theta^T_{re}} \rho^T d\rho^T\right]\right\},$$
$$= \pi^T(\mathcal{G})\left\{1 - \frac{\theta^S_{re}}{l^S l^T}\left[\delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})\theta^T_{re}(1-\frac{1}{q^T}) + \frac{(l^T-\theta^T_{re})^2}{2}\right]\right\},$$
$$= \frac{\pi^T(\mathcal{G})}{l^S l^T}\left\{l^S l^T - \theta^S_{re}\left[\delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})\theta^T_{re}(1-\frac{1}{q^T}) + \frac{(l^T-\theta^T_{re})^2}{2}\right]\right\},$$

Then, the expected payoff for the target under the threat of retaliation is

$$\mathcal{E}^{T,R}_{S,T,r} = \begin{cases} \mathcal{E}^{T,re}_{S,T,r} & \delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T}) < \frac{q^T}{q^T-1}\delta^T(\mathcal{G}-g_{rT\to S}) \\ \mathcal{E}^{T}_{S,T,r} & \delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T}) \geq \frac{q^T}{q^T-1}\delta^T(\mathcal{G}-g_{rT\to S}) \end{cases} \quad (S39)$$

4 Effectiveness of retaliation

We define the effectiveness of retaliation as the reduction in the effectiveness of sanctions under the threat of retaliation, i.e.,

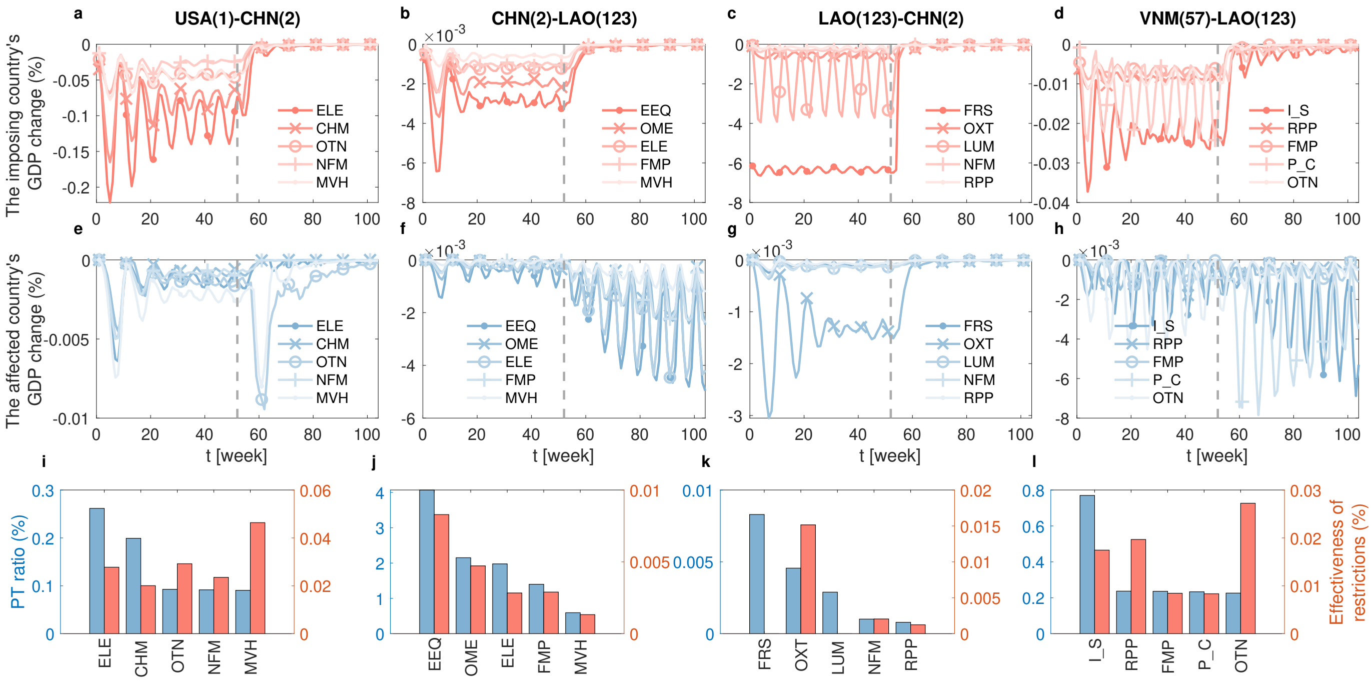
$$\vartheta^R_{S,T,r} = \min\{\max\{1-\frac{\eta^R_{S,T,r}}{\eta_{S,T,r}},0\},1\}$$
$$= \begin{cases} \min\{\max\{1-\frac{\eta^{re}_{S,T,r}}{\eta_{S,T,r}},0\},1\} & \delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T}) < \frac{q^T}{q^T-1}\delta^T(\mathcal{G}-g_{rT\to S}) \\ 0 & \delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T}) \geq \frac{q^T}{q^T-1}\delta^T(\mathcal{G}-g_{rT\to S}) \end{cases} \quad (S40)$$

5 Comparison of the effectiveness of import and export restrictions

Supplementary Fig. 6 presents the GDP loss for the imposing and affected countries during and after the restriction period (Supplementary Fig. 6**a-h**) and the effectiveness of export restrictions (Supplementary Fig. 6**i-l**) when five sectors, in which the affected country's pre-sanction trade-to-GDP (PT) ratio with the imposing country are highest, are affected by export restrictions. Under export restrictions, country i's pre-sanction trade-to-GDP (PT) ratio with country j in sector r is defined as

$$PT_{rj\to i} = \frac{\sum_u Z^*_{rj\to ui}}{\pi^i(\mathcal{G})}, \quad (S41)$$

where $Z^*_{rj\to ui}$ is the trade flow from sector r in country j to sector u in country i before sanctions. Country i's largest pre-sanction trade-to-GDP (LPT) ratio with country j is defined as $LPT_{j\to i} = \max_r PT_{rj\to i}$. Compared with import restrictions (Fig. 2 in the main text), export restrictions inflict higher economic costs on the imposing countries while lower costs on the affected country, leading to significantly lower effectiveness of restrictions.



Supplementary Figure 6: The economic impact of export restrictions. **a-h**, The imposing country and affected country's GDP change during and after the restriction period. Export restrictions are imposed (**a**) by the US on China, (**b**) by China on Laos, (**c**) by Laos on China, and (**d**) by Vietnam on Laos, respectively. Sectors with the top five largest PT ratios with the sender for the target are selected. The grey dashed line indicates when the restrictions end. The titles are in the form of "the imposing country (pre-sanction GDP rank of the imposing country)-the affected country (pre-sanction GDP rank of the affected country)." **i-l**, The affected country's PT ratios with the imposing country (blue bars) and the effectiveness of import restrictions (red bars) under the corresponding sanction scenario. PT ratio: pre-sanction trade-to-GDP ratio. ISO country codes: USA, United States; CHN, China; LAO, Laos; VNM, Vietnam. Sectors are presented with three-letter codes. The description of sector codes can be found in Supplementary Material.

6 Proof of propositions

We establish the following corollaries based on findings in the main text.

Supplementary Corollary 1. If $LPT_{j\to i} < LPT_{j\to i'}$, $\pi^j(\tilde{\mathcal{G}} - g_{rj\to i}) > \pi^j(\tilde{\mathcal{G}} - g_{r'j\to i'})$. $\tilde{\mathcal{G}}$ is the global supply chain network at any game stage.

Supplementary Corollary 2. If $LPT_{j\to i} \to 0$, $\pi^j(\tilde{\mathcal{G}} - g_{rj\to i}) \approx \pi^j(\tilde{\mathcal{G}})$.

Supplementary Corollary 3. If country i imposes sanctions/retaliation on country j, sanctions/retaliation are more likely to be effective if $\pi^i(\tilde{\mathcal{G}} - g_{rj\to i}) \approx \pi^i(\tilde{\mathcal{G}})$.

Under **Supplementary Corollaries 1-3**, we have the following proposition.

Supplementary Proposition 1. Given $\delta^S(\mathcal{G} - g_{rT\to S})$ and $\delta^T(\mathcal{G} - g_{rT\to S})$, if $\vartheta^R_{S,T,r} \in (0,1)$, $\vartheta^R_{S,T,r} \propto \delta^S(\mathcal{G} - g_{rT\to S} - g^R_{S\to T})$.

Proof of Supplementary Proposition 1. When $\vartheta^R_{S,T,r} \in (0,1)$, the effectiveness of retaliation is

$$\vartheta^R_{S,T,r} = 1 - \frac{\eta^{re}_{S,T,r}}{\eta_{S,T,r}}, \tag{S42}$$

where

$$\eta_{S,T,r} = \left[1 - \frac{\min\{(q^S - 1)\delta^S(\mathcal{G} - g_{rT\to S}), l^S\}}{l^S}\right] \frac{\min\{\delta^T(\mathcal{G} - g_{rT\to S}), l^T\}}{l^T}, \tag{S43}$$

and

$$\eta^{re}_{S,T,r} = \left[1 - \frac{\min\{q^S\delta^S(\mathcal{G} - g_{rT\to S} - g^R_{S\to T}) - \delta^S(\mathcal{G} - g_{rT\to S}), l^S\}}{l^S}\right] \frac{\min\{\delta^T(\mathcal{G} - g_{rT\to S} - g^R_{S\to T})\frac{q^T-1}{q^T}, l^T\}}{l^T}. \tag{S44}$$

Denote

$$\begin{aligned}\delta^S(\mathcal{G}-g_{rT\to S}) &:= \mathcal{D}^S,\\ \delta^S(\mathcal{G}-g_{rT\to S}-g^R_{S\to T}) &:= \mathcal{D}^S_R,\\ \delta^T(\mathcal{G}-g_{rT\to S}) &:= \mathcal{D}^T,\\ \delta^T(\mathcal{G}-g_{rT\to S}-g^R_{S\to T}) &:= \mathcal{D}^T_R,\end{aligned}$$

then,

$$\vartheta^R_{S,T,r} = 1-\frac{\eta^{re}_{S,T,r}}{\eta_{S,T,r}} = 1-\frac{[1-\min\{\frac{q^S\mathcal{D}^S_R-\mathcal{D}^S}{l^S},1\}]\min\{\frac{(q^T-1)\mathcal{D}^T_R}{l^Tq^T},1\}}{[1-\min\{\frac{(q^S-1)\mathcal{D}^S}{l^S},1\}]\min\{\frac{\mathcal{D}^T}{l^T},1\}}.$$

Under **Supplementary Corollary 3**, we have $\mathcal{D}^S\approx 0$ and $\mathcal{D}^T\approx\mathcal{D}^T_R$, thus,

$$\vartheta^R_{S,T,r}\approx 1-\frac{[1-\min\{\frac{q^S\mathcal{D}^S_R}{l^S},1\}]\min\{\frac{(q^T-1)\mathcal{D}^T}{l^Tq^T},1\}}{\min\{\frac{\mathcal{D}^T}{l^T},1\}}.$$

Since $\vartheta^R_{S,T,r}\in(0,1)$, we have $\mathcal{D}^S_R<\frac{l^S}{q^S}$, and

$$\vartheta^R_{S,T,r}\approx 1-[1-\frac{q^S\mathcal{D}^S_R}{l^S}]\frac{\min\{\frac{(q^T-1)\mathcal{D}^T}{l^Tq^T},1\}}{\min\{\frac{\mathcal{D}^T}{l^T},1\}}.$$

Given $\mathcal{D}^S$ and $\mathcal{D}^T$, $\vartheta^R_{S,T,r}\propto\mathcal{D}^S_R$.

Proof of Proposition 2 Under short-term individual retaliation strategies, $\pi^S(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})=\pi^S(\mathcal{G}-g_{rT\to S}-g_{uS\to T})$. With **Supplementary Corollaries 1-3**, we have

$$\pi^S(\mathcal{G}-g_{rT\to S}-g_{uS\to T})\approx\pi^S(\mathcal{G}-g_{uS\to T})>\pi^S(\mathcal{G}-g_{u\prime S\to T\prime})\approx\pi^S(\mathcal{G}-g_{rT\to S}-g_{u\prime S\to T\prime}), \tag{S45}$$

if $LPT_{S\to T}<LPT_{S\to T\prime}$. Thus, under the assumption of **Supplementary Proposition 1**, we have

$$\vartheta^R_{S,T,r}<\vartheta^R_{S,T\prime,r}, \tag{S46}$$

if $LPT_{S\to T}<LPT_{S\to T\prime}$, indicating that individual retaliation strategies are more effective under the high bilateral (high $LPT_{S\to T}$) than the high unilateral (low $LPT_{S\to T}$) interdependence scenarios.

Proof of Proposition 3 We assume that there is only one major contributor (country m) in the bloc, i.e., $LPT_{S\to m}>0$ and $LPT_{S\to c}\to 0$ for $c\in\mathcal{B}\setminus m$. Under the high bilateral interdependence scenario, the target country is the major contributor, thus based on **Supplementary Corollary 2**, we have

$$\pi^S(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})\approx\pi^S(\mathcal{G}-g_{rT\to S}-g_{uS\to T}). \tag{S47}$$

While under the unilateral interdependence scenario,

$$\pi^S(\mathcal{G}-g_{rT\to S}-g^R_{S\to T})\approx\pi^S(\mathcal{G}-g_{rT\to S}-g_{u\prime S\to m})<\pi^S(\mathcal{G}-g_{rT\to S}-g_{uS\to T}). \tag{S48}$$

Under the assumption of **Supplementary Proposition 1**, we have $\vartheta^{R,C}_{S,T,r}\approx\vartheta^{R,I}_{S,T,r}$ under the high bilateral interdependence scenario, while $\vartheta^{R,C}_{S,T,r}>\vartheta^{R,I}_{S,T,r}$ under the high unilateral interdependence scenario. Here, $\vartheta^{R,C}_{S,T,r}$ and $\vartheta^{R,I}_{S,T,r}$ are the effectiveness of collective and individual retaliation strategies.

Supplementary Table 1: GTAP sector classification

Sector Code	Sector Name
pdr	Rice

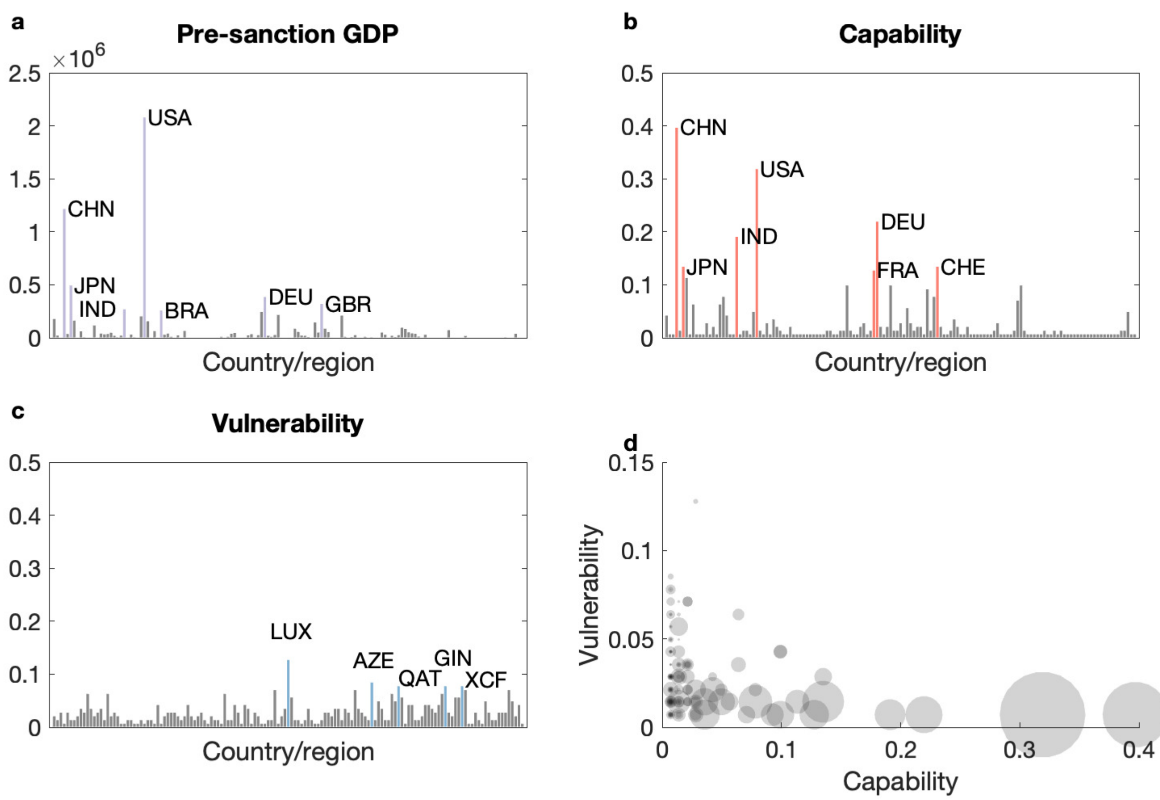
wht	Wheat
gro	Other Grains
v_f	Veg & Fruit
osd	Oil Seeds
c_b	Cane & Beet
pfb	Fibres crops
ocr	Other Crops
ctl	Cattle
oap	Other Animal Products
rmk	Raw milk
wol	Wool
frs	Forestry
fsh	Fishing
coa	Coal
oil	Oil
gas	Gas
oxt	Other Mining Extraction
cmt	Cattle Meat
omt	Other Meat
vol	Vegetable Oils
mil	Milk
pcr	Processed Rice
sgr	Sugar and molasses
ofd	Other Food
b_t	Beverages and Tobacco products
tex	Manufacture of textiles
wap	Manufacture of wearing apparel
lea	Manufacture of leather and related products
lum	Lumber
ppp	Paper & Paper Products
p_c	Petroleum & Coke
chm	Manufacture of chemicals and chemical products
bph	Manufacture of pharmaceuticals, medicinal chemical and botanical products
rpp	Manufacture of rubber and plastics products
nmm	Manufacture of other non-metallic mineral products
i_s	Iron & Steel
nfm	Non-Ferrous Metals
fmp	Manufacture of fabricated metal products, except machinery and equipment
ele	Manufacture of computer, electronic and optical products
eeq	Manufacture of electrical equipment
ome	Manufacture of machinery and equipment n.e.c.
mvh	Manufacture of motor vehicles, trailers and semi-trailers
otn	Manufacture of other transport equipment
omf	Other Manufacturing: includes furniture
ely	Electricity; steam and air conditioning supply
gdt	Gas manufacture, distribution
wtr	Water supply; sewerage, waste management and remediation activities
cns	Construction
trd	Wholesale and retail trade; repair of motor vehicles and motorcycles
afs	Accommodation, Food and service activities
otp	Land transport and transport via pipelines

wtp	Water transport
atp	Air transport
whs	Warehousing and support activities
cmn	Information and communication
ofi	Other Financial Intermediation
ins	Insurance
rsa	Real estate activities
obs	Other Business Services nec
ros	Recreation & Other Services
osg	Other Services (Government)
edu	Education
hht	Human health and social work
dwe	Dwellings

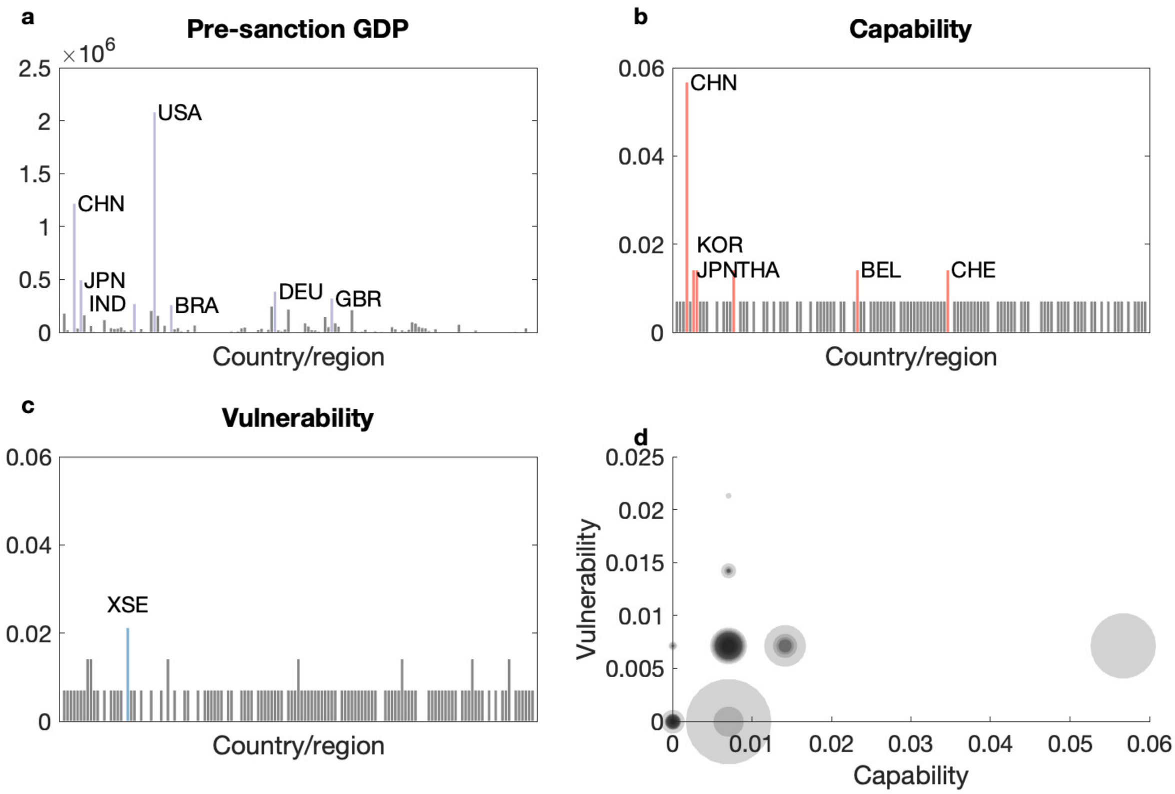
Supplementary Table 2: Country codes list

Code	Name	Code	Name
USA	United States	CHN	China
JPN	Japan	DEU	Germany
GBR	United Kingdom	FRA	France
IND	India	BRA	Brazil
ITA	Italy	RUS	Russia
LAO	Laos	VNM	Vietnam
CHE	Switzerland	BRN	Brunei Darussalam
IDN	Indonesia	SGP	Singapore
LUX	Luxembourg	KWT	Kuwait
BOL	Bolivia	GIN	Guinea

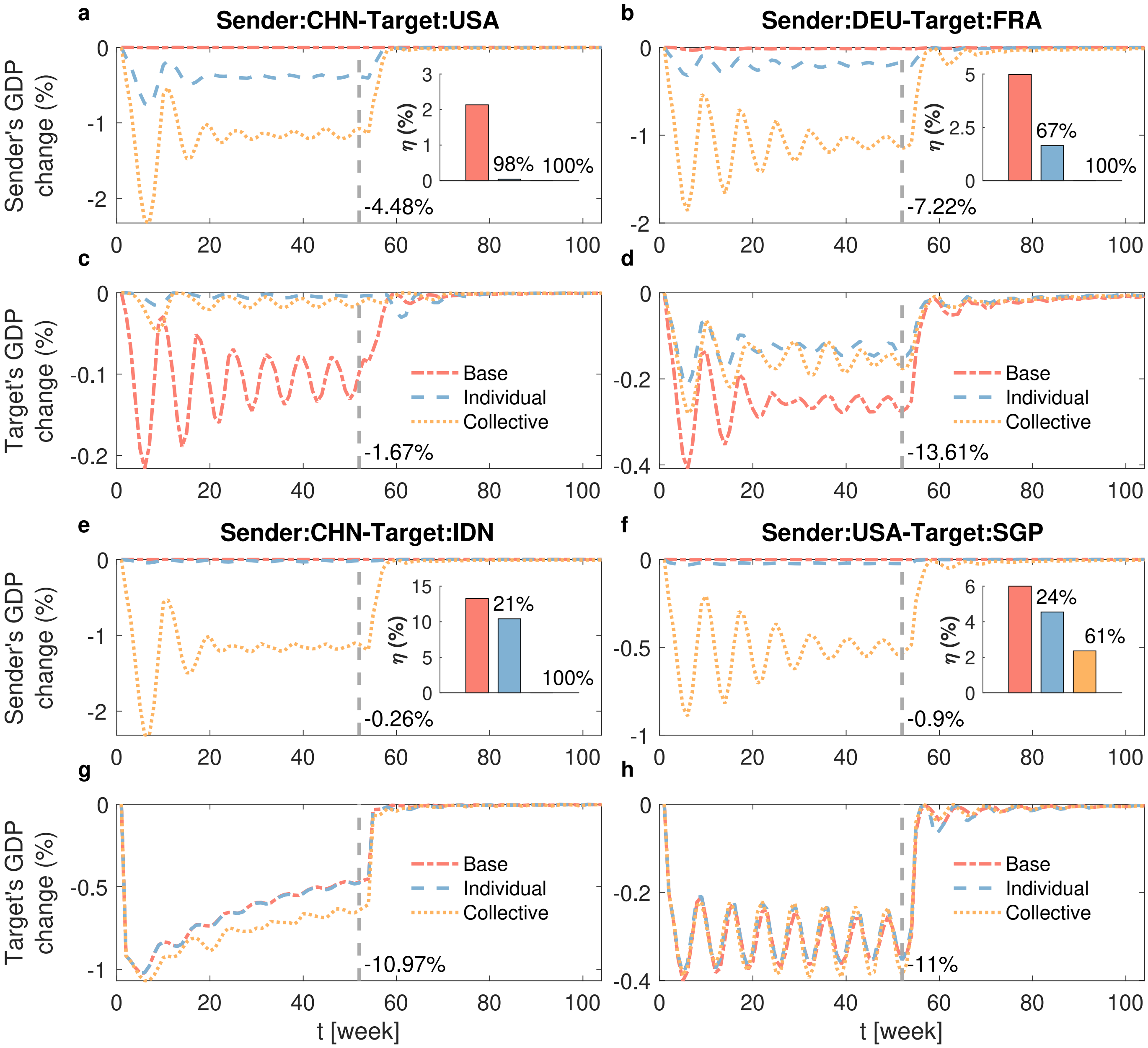
Codes for other countries can be found in
`https://www.iso.org/iso-3166-country-codes.html` and
`https://www.gtap.agecon.purdue.edu/databases/regions.aspx?version=10`



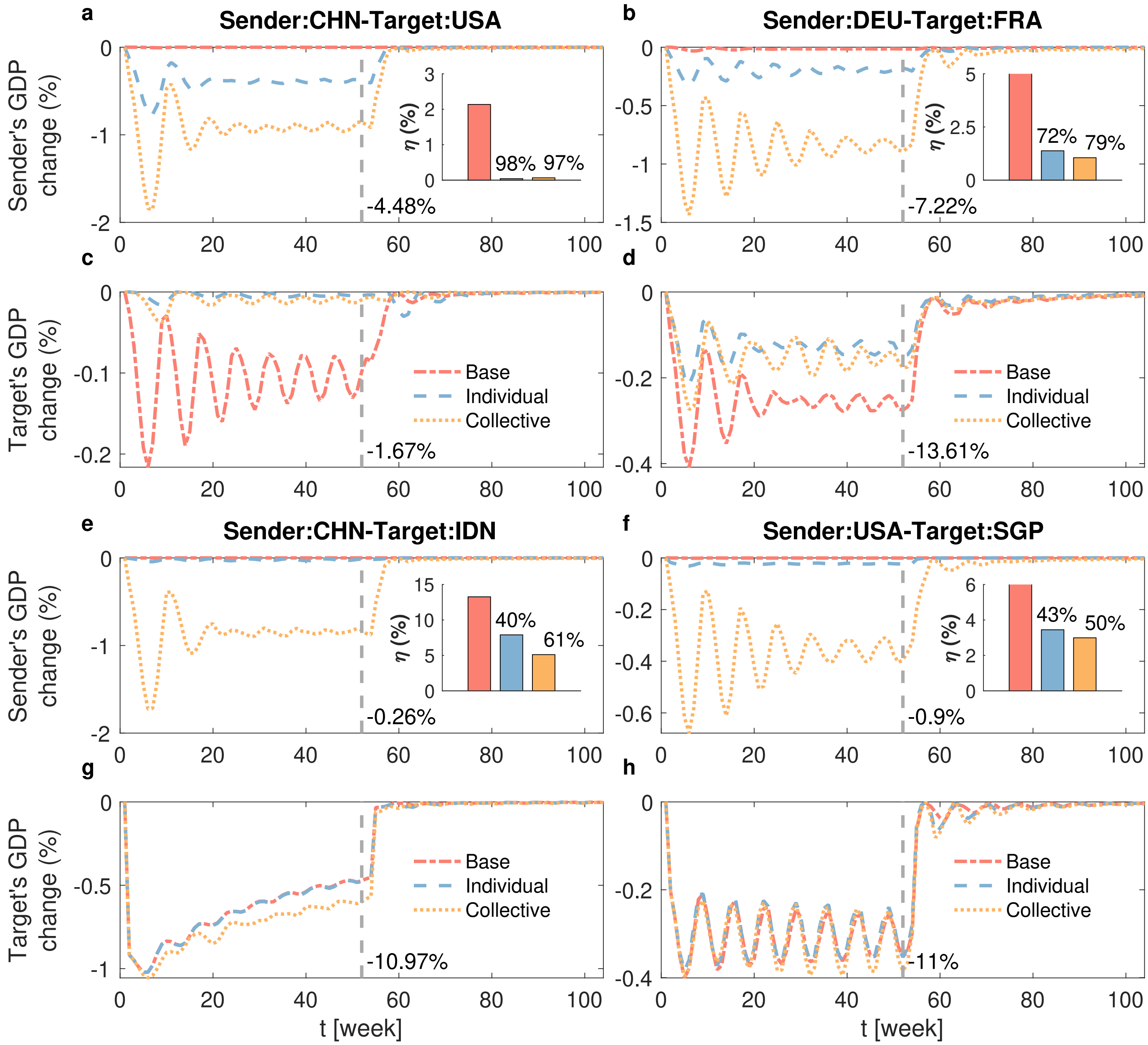
Supplementary Figure 7: Capability of imposing economic sanctions and vulnerability to economic sanctions. The pre-sanction GDP (**a**), the capability of imposing economic sanctions (**b**), and the vulnerability to economic sanctions (**c**) for each country/region. Countries/regions with values in the 95% percentile are highlighted. Each point in the scatter plot (**d**) represents a country/region. The size of the point is proportional to the country/region's pre-sanction GDP. Three-letter codes for countries/regions are used for clear illustration. The description of country/region codes can be found in Supplementary Material. $L\hat{P}T = 0.01$.



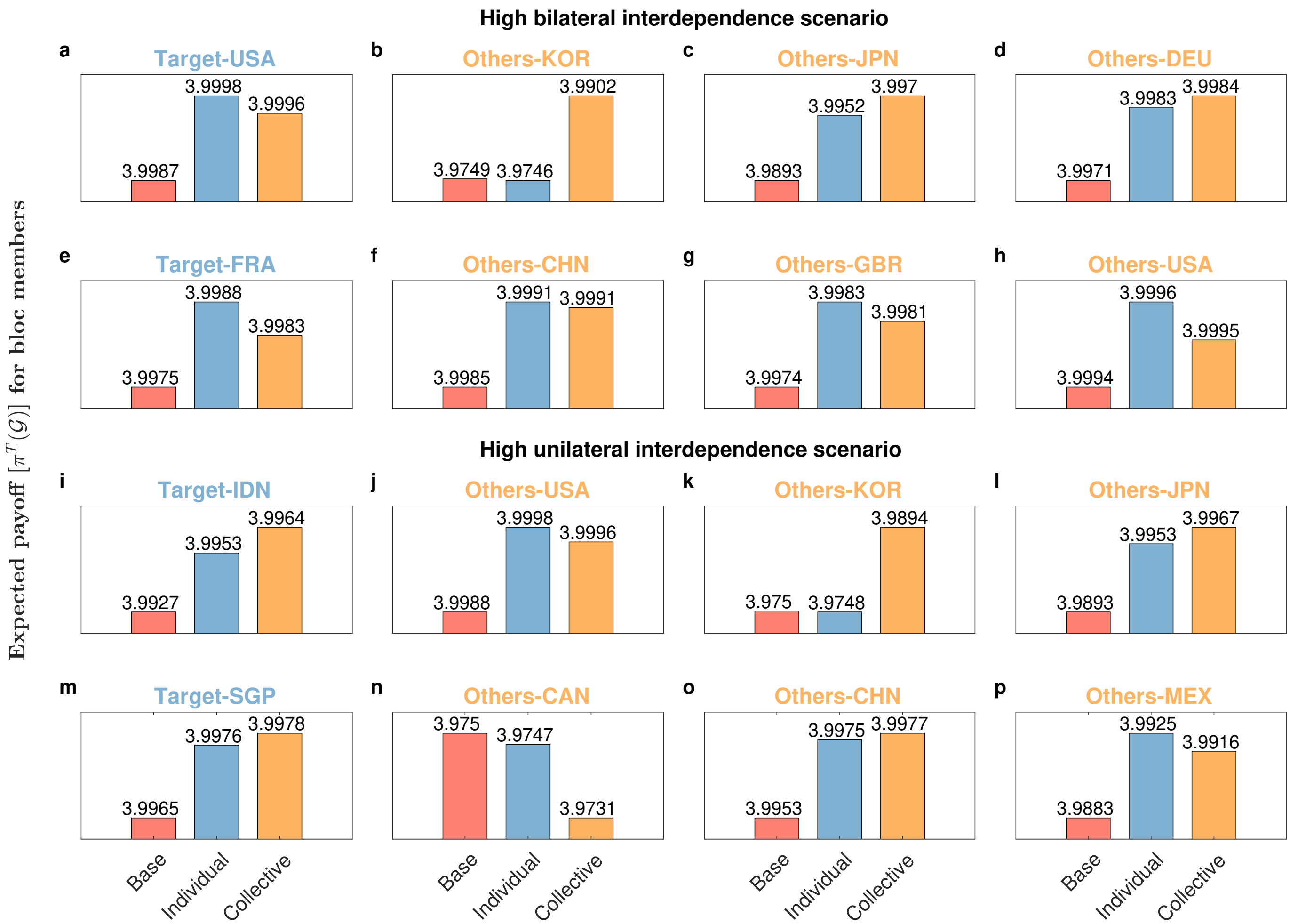
Supplementary Figure 8: Capability of imposing economic sanctions and vulnerability to economic sanctions. The pre-sanction GDP (**a**), the capability of imposing economic sanctions (**b**), and the vulnerability to economic sanctions (**c**) for each country/region. Countries/regions with values in the 95% percentile are highlighted. Each point in the scatter plot (**d**) represents a country/region. The size of the point is proportional to the country/region's pre-sanction GDP. Three-letter codes for countries/regions are used for clear illustration. The description of country/region codes can be found in Supplementary Material. $L\hat{P}T = 0.1$.



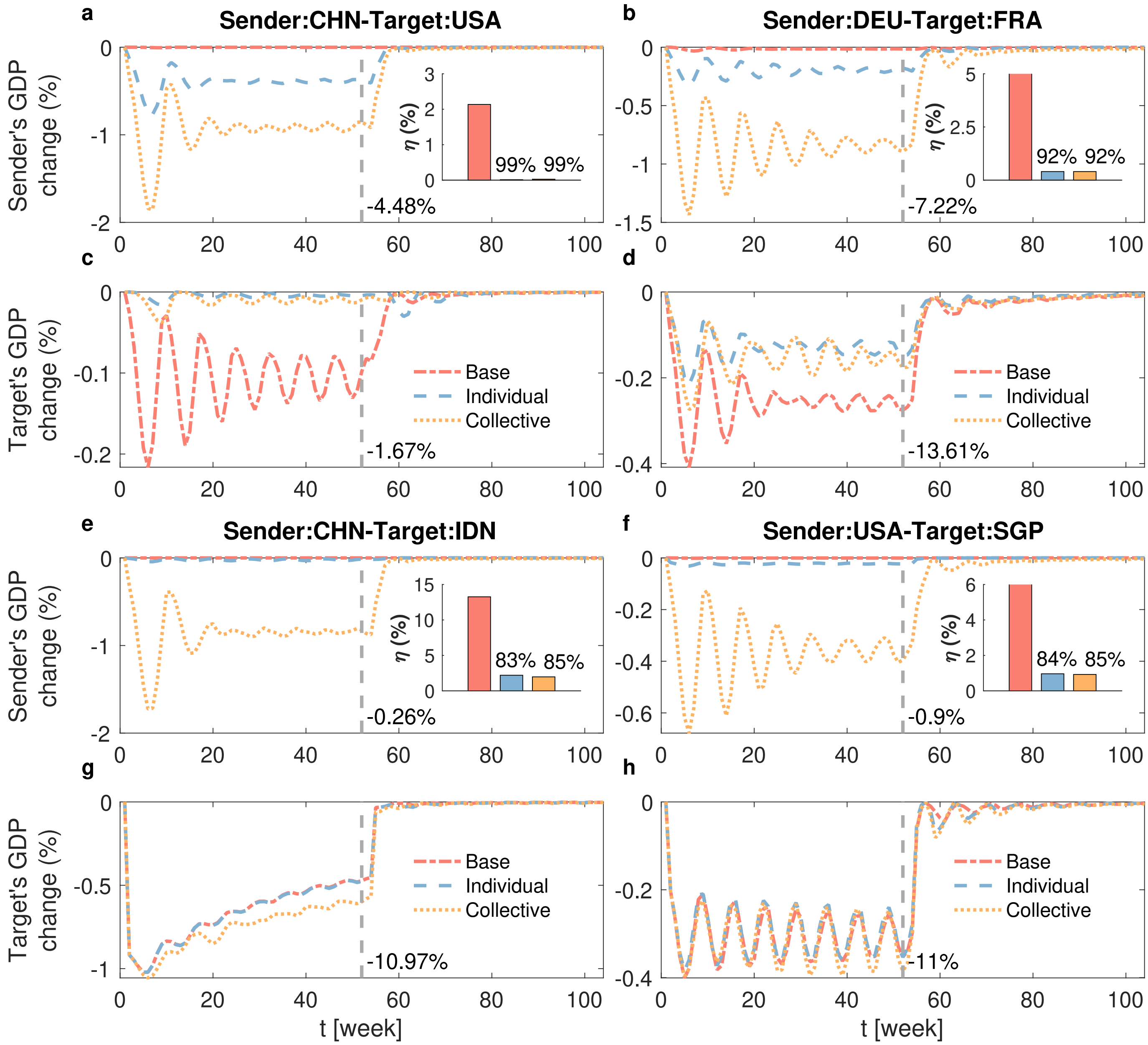
Supplementary Figure 9: The effectiveness of retaliation. The sender and target's GDP change during and after sanctions imposed by China on the US (**a** and **c**), by Germany on France (**b** and **d**), by China on Indonesia (**e** and **g**), and by the US on Singapore (**f** and **h**), respectively. Three-letter codes for countries/regions are used for clear illustration. The target will not retaliate (base) or adopt individual short-term retaliation (individual) or collective short-term retaliation (collective) strategies if the sender imposes sanctions. The grey dash line indicates when the sanctions end. The number close to the grey dashed line is the reduction in GDP for the sender/target in equilibrium after decoupling. The inset in **a**, **b**, **e**, and **f** shows the effectiveness of sanctions under the no (i.e., base; red), individual (blue), and collective (orange) retaliation strategies. The numbers above the blue and orange bars are the effectiveness of the individual and collective retaliation strategies. The number of countries in a bloc is five. $q^S = q^T = 5$.



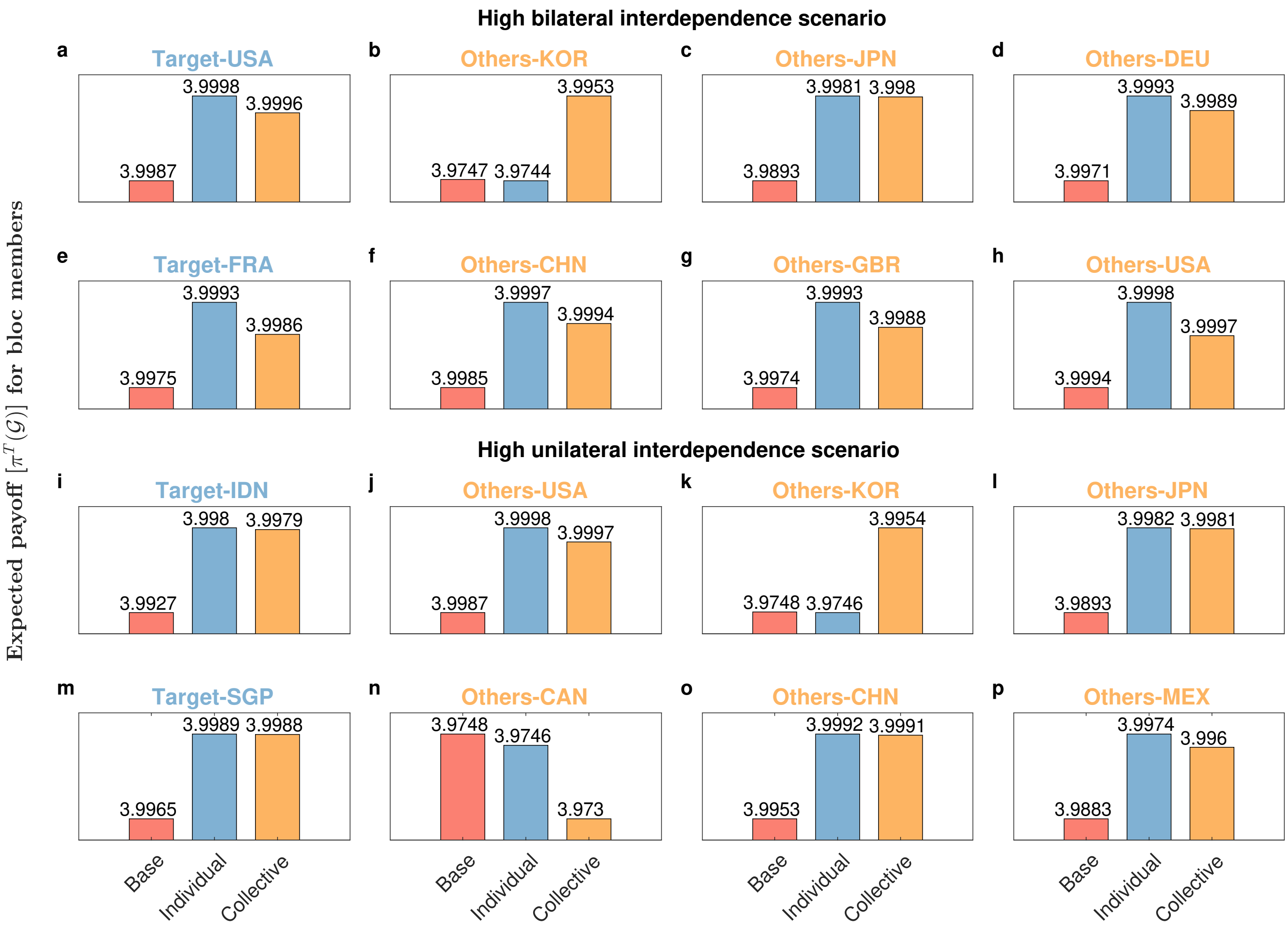
Supplementary Figure 10: The effectiveness of retaliation. The sender and target's GDP change during and after sanctions imposed by China on the US (**a** and **c**), by Germany on France (**b** and **d**), by China on Indonesia (**e** and **g**), and by the US on Singapore (**f** and **h**), respectively. Three-letter codes for countries/regions are used for clear illustration. The target will not retaliate (base) or adopt individual short-term retaliation (individual) or collective short-term retaliation (collective) strategies if the sender imposes sanctions. The grey dash line indicates when the sanctions end. The number close to the grey dashed line is the reduction in GDP for the sender/target in equilibrium after decoupling. The inset in **a**, **b**, **e**, and **f** shows the effectiveness of sanctions under the no (i.e., base; red), individual (blue), and collective (orange) retaliation strategies. The numbers above the blue and orange bars are the effectiveness of the individual and collective retaliation strategies. The number of countries in a bloc is three. $q^S = q^T = 2.5$.



Supplementary Figure 11: Willingness to join a bloc. The expected payoff of joining (adopting the collective short-term retaliation strategy) and not joining (adopting the base/no and individual retaliation strategies) the bloc for countries in a potential bloc under the high bilateral trade relationship (**a-h**) and the high unilateral trade relationship (**i-p**) scenarios. Countries in the same row are in a potential bloc. Three-letter codes for countries/regions are used for clear illustration. The value of each bar is shown on the top of each bar. The number of countries in a bloc is three. $q^S = q^T = 2.5$.



Supplementary Figure 12: The effectiveness of retaliation. The sender and target's GDP change during and after sanctions imposed by China on the US (**a** and **c**), by Germany on France (**b** and **d**), by China on Indonesia (**e** and **g**), and by the US on Singapore (**f** and **h**), respectively. Three-letter codes for countries/regions are used for clear illustration. The target will not retaliate (base) or adopt individual short-term retaliation (individual) or collective short-term retaliation (collective) strategies if the sender imposes sanctions. The grey dash line indicates when the sanctions end. The number close to the grey dashed line is the reduction in GDP for the sender/target in equilibrium after decoupling. The inset in **a**, **b**, **e**, and **f** shows the effectiveness of sanctions under the no (i.e., base; red), individual (blue), and collective (orange) retaliation strategies. The numbers above the blue and orange bars are the effectiveness of the individual and collective retaliation strategies. The number of countries in a bloc is three. $q^S = q^T = 1.2$.



Supplementary Figure 13: Willingness to join a bloc. The expected payoff of joining (adopting the collective short-term retaliation strategy) and not joining (adopting the base/no and individual retaliation strategies) the bloc for countries in a potential bloc under the high bilateral trade relationship (**a-h**) and the high unilateral trade relationship (**i-p**) scenarios. Countries in the same row are in a potential bloc. Three-letter codes for countries/regions are used for clear illustration. The value of each bar is shown on the top of each bar. The number of countries in a bloc is three. $q^S = q^T = 1.2$.

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