Network theory meets history. Local balance in global international relations

Fernando Diaz-Diaz[1], Paolo Bartesaghi[2] and Ernesto Estrada[1*]

[1]Institute of Cross-Disciplinary Physics and Complex Systems, IFISC (UIB-CSIC), 07122 Palma de Mallorca, Spain.
[2]Department of Statistics and Quantitative Methods, University of Milano - Bicocca, Via Bicocca degli Arcimboldi 8, 20126, Milano, Italy.

*Corresponding author(s). E-mail(s): estrada@ifisc.uib-csic.es;
Contributing authors: fernandodiaz@ifisc.uib-csic.es;
paolo.bartesaghi@unimib.it;

Abstract

The resulting effect of global international relations is an intricate and dynamic web of alliances and conflicts. Here, we represent this web as a time-evolving signed network and define an index quantifying the proximity of every nation to its balanced condition. This condition emerges when a given nation belongs to a bloc of allies that only have enmities with a different confronted bloc. However, we find that large blocs of allies percolated by a tiny clique of mutual enemies, which are ubiquitous across history, are very unstable in terms of their balanced condition. We design a quantitative history approach to identify the nations playing a fundamental role in major events in human history over a period of almost 200 years. It is combined with historic narrative and the sociopolitical theory of "balance of power" to build up a new mixed approach to history based on network theory.

Keywords: signed geopolitical networks; international relations; balance; quantitative history; international conflicts; world history

The use of quantitative methods in history is not new. The term "cliometrics", popularized in the 1950s and 1960s, refers to the application of statistics as a systematic general theory to the study of history [1, 2]. Nowadays, the term "quantitative history" [3] is defined "as the application of quantitative methods (such as statistical analysis or modeling, network analysis, or big data processing) to history". Another approach, coined "cliodynamics" [4], focuses on the study of temporally varying historical processes and the search for their causal mechanisms. In this context, network theory has become one of the fastest-growing approaches to understanding international politics [5–13]. This approach exploits the fact that historic events take place on an intricate network of interdependencies between nations, forming a complex system of international relations (IR) [14]. These webs of nation's alliances and enmities can give rise to the emergence of unintended structures. For instance, if the enemy of the enemy of a given nation is its ally, the two allies can form a coalition against the other nation. The analysis of such structures in a network as a whole was first postulated by Heider [15, 16], and is known as balance theory. Nowadays, balance theory is a well-established mathematical concept, which is mainly used to understand how social interactions promote the formation of stable, although not necessarily conflict-free, social groups [17–22].

The quantitative analysis of historic data contrasts with the classical research methodology in history, which focuses on textual records, archival research and the narrative as a form of historical writing [2]. This "qualitative analysis" is based on "the telling of a story to explain and analyze events and human agency in order to increase understanding" [23]. The own subdivision of methods into "quantitative" and "qualitative" ones reflexes certain divorce between both approaches. On one side, quantitative historians consider particular events as an element in the global universe of all the affairs in such a category [2]. On the other, qualitative historians mainly produce narratives of individual historic events. Therefore, there is a necessity for bridging both types of approaches to IR analysis into a "mixed method", which "combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study" [24, 25].

Here, we propose an index that characterizes the local balance of a given nation in a web of IR. At the end of the day, IR are made by the individual nations and the network of their alliances and conflicts; thus, it is necessary to characterize the local balance of every individual nation at a given historic period. We design an approach to identify the major players which are responsible for low levels of local balance on the web, as well as a new methodology to detect abrupt changes in the values of local balances, the players affected by these drops or increases in balance conditions and the corresponding years. Focusing on the networks of IR between countries in the world for the period between 1816 and 2014, we show that the local balance index is very effective in recognizing major historic events of a geopolitical nature. Our approach clearly identifies almost 3,000 major historic events, among which, to name a few, we found the Egyptian-Ottoman wars, the American civil war and the

Italo-Ethiopian war in the XIX century, the Mexican revolution, the Indochina wars and the Gulf and Yugoslav wars, apart from the two world wars, in the XX century, and the Russo-Georgian war, the Iraq war and the Venezuela crisis in the first part of the XXI century.

Results

Local balance index

To understand the rationale of the local balance index proposed here let us consider the following situation created between Great Britain, France and Russia at the beginning of the XX century. In the period between 1904 and 1906 France and Russia were signatories to the Franco-Russian treaty, while Russia was Britain's number one enemy. From January 30, 1902, at the end of the Meiji period, Japan and Britain form the Anglo-Japanese alliance. In 1904 Russia went to war with Japan. So the situation was as follows. France was allied with Russia in accordance with the Franco-Russian military alliance. Great Britain was an ally of Japan and France, but a staunch enemy of Russia. Therefore, in the signed triangle [26] formed by France, Great Britain and Russia we find two positive ties (alliances) and one negative (enmity) (see Fig. 1 (a)). Suppose then that France supports Russia during the war due to its Franco-Russian alliance. Russia would declare war against its enemy Great Britain who would be supporting Japan due to its Anglo-Japanese military alliance. This situation will make Great Britain enter into a contradiction with its new ally, France, who is at this time an ally of its worst enemy. This is a consequence of the fact that the triangle UK-Russia-France is unbalanced–the product of the signs of its edges is negative (Fig. 1 (b), top panel). The situation would be the same if France supports explicitly Great Britain, which would enter the war against Russia; the Franco-Russian alliance would be broken due to the war against Japan. In fact, if we consider what occurred during the Russo-Japanese war we see that neither France supported Russia during the war nor Great Britain made effective its alliance with Japan, and none of them entered the war. These contradictions would not exist if for instance France and Great Britain were mutual enemies at the time of the Russo-Japanese war, which will be represented by two negative edges in the triangle, making it balanced (Fig. 1 (b),bottom panel). When the network is balanced, it can be split into two parts, such that negative edges connect only states from different factions [27, 28].

We should observe that the triangle UK-Japan-Russia is balanced –the product of the signs of its edges is positive. Therefore, at the individual level, Japan participates in a balanced triangle and in no unbalanced one. Russia and Great Britain participate in one balanced and one unbalanced triangle, and France only participates in an unbalanced one. Thus, not all countries have the same balancing position in a unique historic event. This degree of balance that a node has in a network is what we call here the "local balance" of that node. Such characteristic is not static but dynamic as it can change

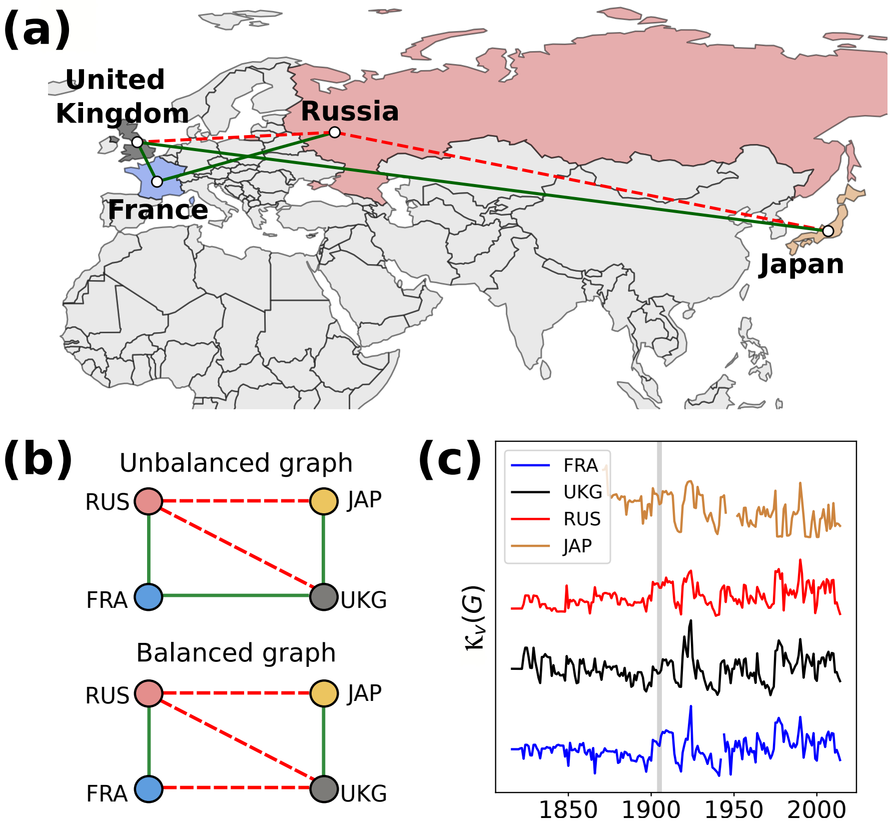


Fig. 1: (a) Illustration of the relations between Great Britain, France, Russia and Japan during the Russo-Japanese war. (b) The mathematical framework for the theory is the representation of IR as signed networks, in which positive edges (green solid lines) represent interstates alliances and negative ones (red dashed lines) are reserved for any kind of conflict/enmities between the parts. (c) Temporal evolution of the "local balance" of the countries in the examined time period. The gray area highlights the years in which the Russo-Japanese war took place.

in time due to different historic circumstances (see Fig. 1 (c)). Although we focused the previous analysis only on triangles, it can be extended to other closed chains (CC), which include squares, pentagons, and so forth.

To quantify this local balance we proceed as follows. The number of CC of length k in which a node v takes place in a signed network G is given by $\left(A^k\right)_{vv}$. This term accounts for the difference between the number of positive CC of length k and the number of negative ones: $(A^k)_{vv}$ = # of positive CC of length k − |# of negative CC of length k|. However, the balance of a node in a CC should depend on the length of that chain. Let us consider a CC of length n with one negative edge $e = \{p, q\}$. Every node

$v \neq p, q$ is at distance i from p and at distance $n-i-1$ $(i = 1, \ldots, n-2)$ from q. This means that the longer the CC, the smaller the average influence of the negative edge on the rest of the nodes of the chain. Therefore, following the analysis performed in similar previous situations [29], we penalize every CC of length k in which a node v takes place in a signed network G by the inverse of the factorial of its length. At this point, we define the local balance index for a node v in a signed network G as

$$\kappa_v(G) := \frac{\sum_{k=0}^{\infty}(A^k)_{vv}/k!}{\sum_{k=0}^{\infty}(|A|^k)_{vv}/k!} = \frac{(\exp A)_{vv}}{(\exp|A|)_{vv}}, \tag{1}$$

where $|A|$ is the entrywise absolute of the adjacency matrix A of the network. For any node v in a network G we have proved (see Supplementary Information) that $0 < \kappa_v(G_n) \leq 1$, where the upper bound is reached for any node in a balanced signed graph and the lower bound is reached asymptotically, for instance, for any node of the fully-negative complete graph when the number of nodes is sufficiently large.

It is worth mentioning here that the sum of $\kappa_v(G)$ for all nodes in the graph is not the same as the global balance index defined in [12]. In the SI we analyze the implications of the cases where the sum of the local balance indices are smaller or greater than the global one.

The fallacies of "Big Blocs" and "local rules"

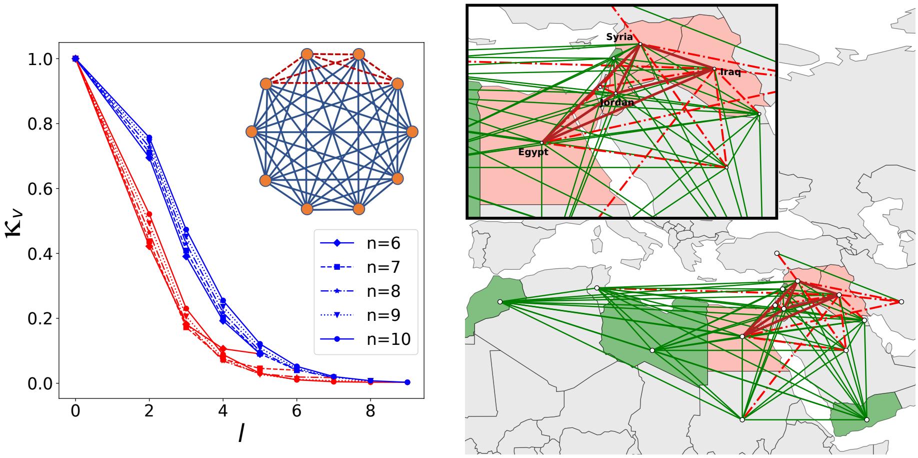
Throughout history, there have been groups of countries united in big blocs by a series of ad hoc mutual alliances. They give the impression of monolithic, stable structures, where the local balance of their members is not significantly altered by the changes occurring in the relations between pairs of countries in the bloc. During the 199-year period studied here, we have observed blocs where a small group of countries have mutual enmities among them but continue to maintain alliances with the rest of the bloc. This is the case, for instance, of the bloc formed by France, Great Britain, Egypt, Yugoslavia, Bulgaria, and Greece in 1939. We can start by considering a bloc of four countries (France, Great Britain, Egypt, and Greece) and six alliances (positive edges). Let us suppose that the bloc wanted to incorporate also Bulgaria and Yugoslavia. The reason is that these two countries have alliances with three of the four members of the bloc (France, Great Britain and Egypt). The two countries have enmities with Greece as well as among themselves. Thus, for every individual country, except for Greece, the number of alliances will increase by two. Based on local rules only, the members of the bloc "see" that incorporating Bulgaria and Yugoslavia will increase the number of alliances by 6, while only 3 negative relations are created. In total, the bloc formed in 1939 by these six countries had 12 positive edges and only 3 negative ones. How stable, from the point of view of local balance, is this situation? The incorporation of Bulgaria and Yugoslavia into the bloc drops the local balance of France, Great Britain and Egypt from one to 0.39 and that of Greece, Bulgaria and Yugoslavia to 0.18. Clearly, it is not a stable situation.

The bloc described before conforms a structure formed by a complete graph K_n in which there is a negative clique $K_{l\leq n-1}$, i.e., $K_n\left(K_l^-\right)$. In the previous example, it corresponded to $K_6\left(K_3^-\right)$. Without making an exhaustive search for this pattern in the global IR, we have found several examples of its existence. For instance, a $K_{16}\left(K_3^-\right)$ was formed in 1955 in Latin America, a $K_{18}\left(K_3^-\right)$ was formed in 2000 during the Balkans war, a $K_{40}\left(K_3^-\right)$ was formed in Africa in 2001 and a $K_{43}\left(K_3^-\right)$ is also present in 2014 in Africa (see SI for countries in the cliques). We can now systematically study the values of $\kappa_v\left(K_n\left(K_l^-\right)\right)$ for the two different types of nodes which exist in these structures (see Fig. 2 (a)). As can be seen, the local balance of both kinds of nodes drops very quickly with the increase of the size of the negative clique, even for the nodes not in the negative clique. In fact, we have mathematically proven that the local balance index drops exponentially fast to zero for any node inside a $K_n(K_l^-)$ structure (see SI). In closing, negative cliques, even if small, have a large influence on the loss of local balance of nodes in signed complete graphs. These results clearly indicate that such "big blocs" are very unstable to the appearance of small negative cliques inside them.

The importance of the $K_n\left(K_l^-\right)$-like structures in certain periods of instability in the global IR is patented in the following example. In 1961 a situation emerged in the Middle East and northern Africa which gave rise to a structure of the type $K_8\left(K_4^-\right)$, which is complexified by other positive and negative relations with other countries in the same geopolitical region. The big bloc was formed by Syria, Iraq, Egypt, Jordan, Yemen, Lebanon, Morocco, and Libya, in which the first four countries formed a negative clique (see Fig. 2 (b)). This scenario emerged during the independence of Kuwait from United Kingdom [30, 31] and the declaration of the Iraqi ruler that Kuwait should be an integral part of Iraq. Iraq threats the new nation with annexation, which ignites an international crisis involving Britain, United States, the Soviet Union and all the Arab states. By September 1961 a contingent of soldiers from Saudi Arabia, Jordan, UAR–formed by Egypt and Syria–, and Sudan had arrived at Kuwait as a consequence of the crisis. The further developments of this coalition and the complicated kaleidoscope of relations between Arab states is detailed in [30]. However, the coalition of intervention ended in its total dissolution by 1963, pointing out to the potential role played by the instability of the structure $K_8\left(K_4^-\right)$ formed in this scenario of IR.

Linking local balance with historical narrative

Due to the necessity of establishing bridges between quantitative methods–like the local balance of IR–and the narrative of historic events, we use here a "mixed method" based on the principles described in [24, 25]. We do so by identifying individual (negative and positive) deviations from the local balance of countries along their historic trajectory (the analysis of the behavior of the local balance of individual countries along the historic period studied is carried



(a) (b)

Fig. 2: (a) Plot of the local balance index for compounded cliques $K_n\left(K_l^-\right)$ where n changes from 6 to 10 and l varies from 2 to $n-1$. The top plots illustrate the local balance of the nodes having no negative edges attached, while the bottom ones correspond to nodes incident to negative edges. (b) Illustration of the complex system of IR between Middle East and northern African countries in 1961. The inset enlarges the subgraph representing the most critical countries in the conflict.

out in the SI). The abrupt appearance of "peaks" in the temporal evolution of the local balance of a given set of countries in one particular year is seen here as a signal of a significant and sudden change in the IR involving these countries. We then retrospectively analyze the historical situation in which these individual countries were involved this year to create a narrative. This analysis reveals some well-known major historic events and their main players, but also some more subtle historic situations.

Historical events dropping local balance.

By applying the methodology described in the Methods Section we identified 1553, 232 and 44 events of low, medium and high level of balance drop, respectively. Hereafter we will focus only on those events with a medium or high balance drop. In the SI we plot the number of events of different levels per year for the period under study (1816-2014). Once we have identified: (i) the drops in local balance, (ii) the corresponding countries involved in them and (iii) their temporal collocation, we relate these results to the historical events that occurred to that country in that year. For space reasons, we indicate only some of the main events, which are split into the three centuries covered by the data to facilitate the narrative.

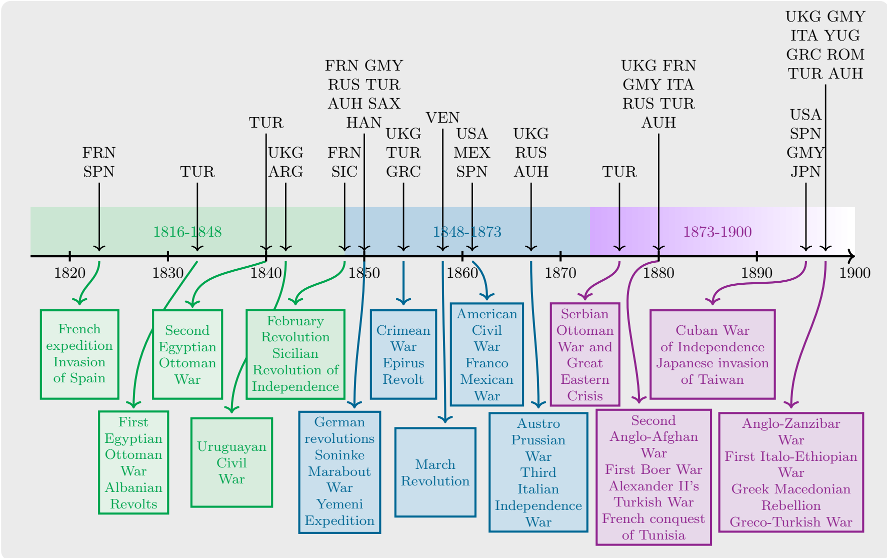


Fig. 3: Timeline of the major events decreasing the local balance detected in the XIX century. A table relating each country to its corresponding code is provided in the Supplementary Information.

XIX century. In Fig. 3 we illustrate the timeline of the main events detected by our methodology in the XIX century.

To bridge these quantitative findings with a historic narrative we will focus on the period 1848-1850, which witnessed the largest and most widespread revolutionary wave in the history of Europe. Historians agree in attributing the February 1848 Revolution in France, which led to the collapse of Monarchy, as the spark that triggered the fire across Europe [32]. The node of France in the IR network is characterized by low values of κ_v in its whole recent history, but in the years preceding the revolution of 1848, the value of κ_v was around 0.40. In 1848 it drops to 0.25 and in 1850 to 0.13. In the meanwhile, the uprisings spread throughout Europe, in particular in the Italian and German states. In the early months of 1848, the Sicilian Revolution took place and the value of κ_v associated with the no longer existing Kingdom of the Two Sicilies plunges from a value of 0.96 in 1847 to a value of 0.22 in 1848.

In 1849 there is a general increase in the κ_v values for all states then in existence, but again in 1850 we see a new crash. In fact, the German revolutions of 1848-1849 attempted to transform the Confederation into a unified German Federal State; but in 1850 the Diet was re-established after the revolution was crushed by Austria and Prussia [33]. This is observed by the sharp drops in the values κ_v of many German States: Kingdoms of Saxony and of Hanover, both drop from 0.97 in 1849 to 0.41 in 1850, Kingdoms of Bavaria and of Württenberg from 0.70 to 0.38 and Grand Duchy of Baden from 0.70 to 0.38. Surprisingly, the links of Hanover, Saxony and the Grand Duchy of

Baden in 1850, are all positive! And other German countries involved in such revolutions have at most one negative edge only. Therefore, the local balance index manages to capture the situation of local instability much better than other local network indicators, such as the number of negative edges attached to every country.

XX century. Let us now move to the XX century. In Fig. 4 we illustrate the identification of the major historical events made by the current method.

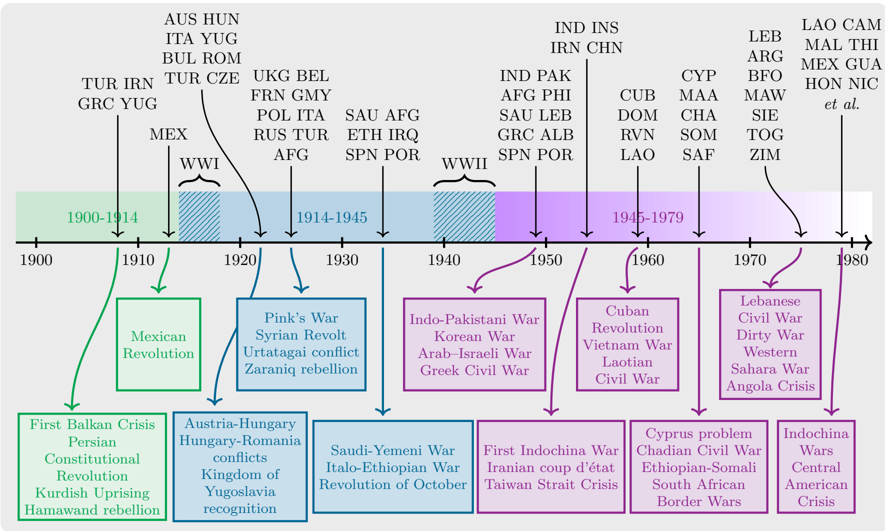


Fig. 4: Timeline of the major events decreasing the local balance detected in the XX century. A table relating each country to its corresponding code is provided in the Supplementary Information.

A dramatic drop in the value of the local balance index is witnessed by Mexico in 1913 and 1917. The κ_v values for Mexico in the early years of the XX century averaged around 0.96. However, in 1913 this value suddenly collapsed to 0.44 and to 0.37 in 1917. In 1912 Mexico's only link to the global network is through the U.S., which is a negative edge. In 1913 the IR of Mexico are described by the subgraph illustrated in Fig. 5. The majority of the edges in Fig. 5 are negative. The imbalance observed here is predominantly produced by the two negative triangles Mexico-USA-Germany and Mexico-UK-Germany. Therefore, there is a key role played by Germany in unbalancing the IR concerning Mexico in 1913. If the Germany-Mexico link were positive, the balance of this subgraph would significantly increase.

Let us now discuss the political events that happened in Mexico during this period. In February 1913, army generals from the deposed president Porfirio Diaz staged a coup d'état in Mexico City, forcing President Madero to resign. This event triggered a bloody development of the Mexican revolution, placing

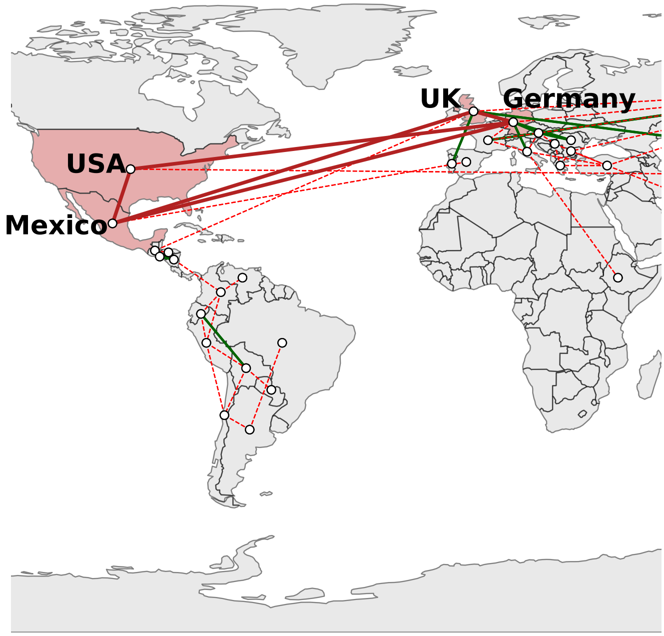


Fig. 5: Illustration of the IR involving Mexico at the beginning of the XX century.

Victoriano Huerta as the new president [34]. Although the revolutionary conflict was primarily a civil war, foreign powers and private companies, having important economic and strategic interests in Mexico, played a remarkable role [35]. On one side, Germany was trying to deliver arms to the Huerta regime, to which the U.S. was opposed and acted by the seizure and occupation of the port of Veracruz to avoid the arming of Huerta's forces from the German side [36]. Since Huerta did not seize power until February 1913, Germany was during the beginning of that year an ally of a rebel and therefore an enemy of the Mexican government. With the outbreak of World War I in Europe, Germany attempted to draw Mexico into war with the United States, which was itself neutral at the time. On the other hand, Germany hoped to draw the U.S. troops from deployment in Europe and, as a reward in the case of German victory, to return to Mexico the territory that it lost in the Mexican-American War. Therefore, the negative edge Germany-Mexico disappeared after 1913, as Germany now conspired to inflame Mexico against the U.S. The leaking of this information pushed the U.S. into war against Germany in 1917. The German activities in Mexico, although "relatively unnoticed by historians until recently" [35], were decisive for the events surrounding the entry of the United States into the First World War. These events show how, even without large-scale war interventions, Germany played a key role in destabilizing Mexico and significantly dropping its local balance indicator.

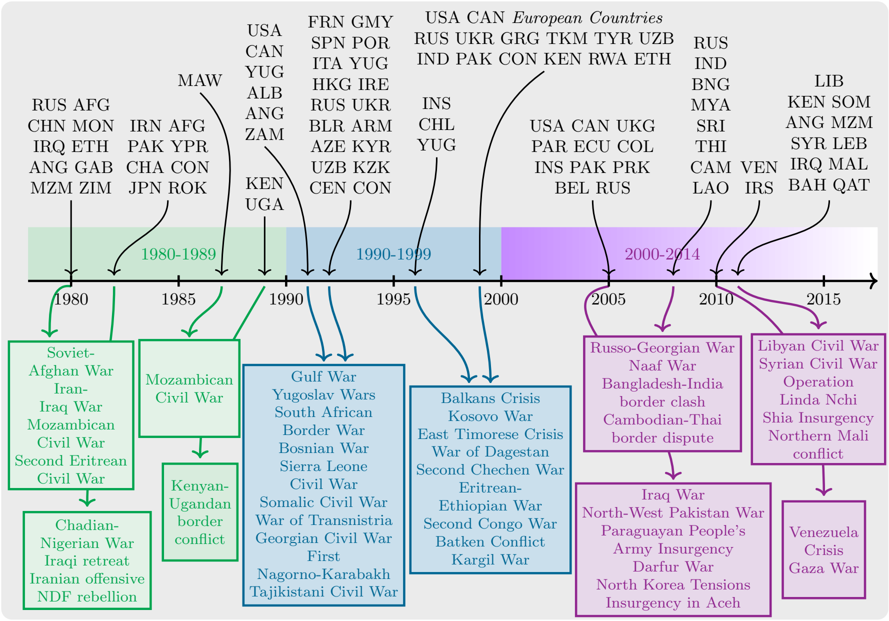


Fig. 6: Timeline of the major events decreasing the local balance detected in the end of the XX century and beginning of the XXI century. A table relating each country to its corresponding code is provided in the Supplementary Information.

XXI century. In Fig. 6 we illustrate the identification of the major historical events made by the current method for the late XX century and early XXI century.

Here we focus on the Venezuelan economic crisis and how this destabilized its IR by dropping dramatically its local balance. Venezuela exhibits a very low local balance for the entire period, from the end of World War II to the present, with an average of 0.25. Nevertheless, in 2009 its value was 0.40, followed by a dramatic drop the year after to a value of 0.008, one of the lowest values ever recorded for all countries and for all years analyzed. In 2009, Venezuela was well established in the South American cluster with only two negative edges, one with Colombia and another with Guyana, and, very importantly, with a positive edge with the U.S. In 2009 the link with the U.S. represents for Venezuela a bottleneck through which it connects to the rest of the world, outside South America. Now, in 2010 it happens that this link suddenly becomes negative as can be seen in Fig. 7, and this is the only difference with the previous years. All the edges within the South American cluster preserve their sign from 2009 to 2010.

The events started with a deep banking crisis in the transition from 2009 to 2010 linked to episodes of corruption in the government of Hugo Chávez. The

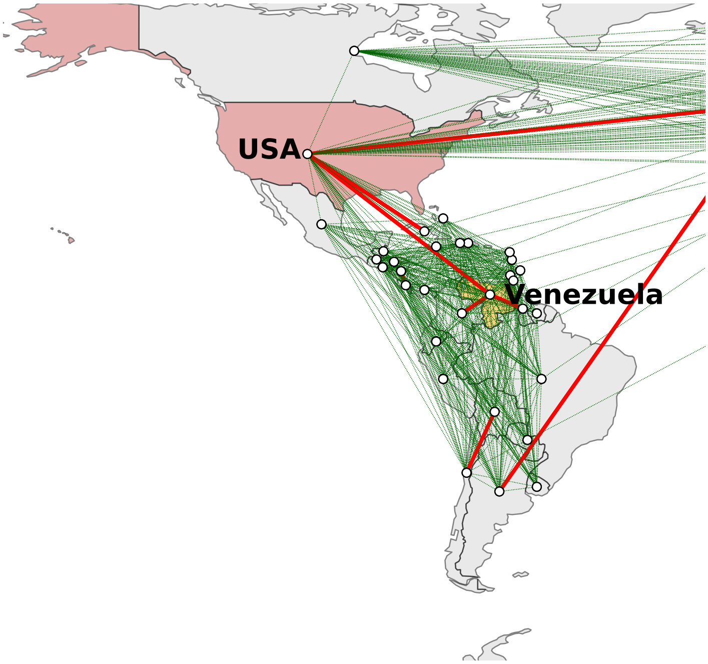


Fig. 7: Illustration of the IR involving Venezuela in 2009.

second aspect is related to an out-of-control rise in inflation and an unprecedented escalation of starvation, disease, crime and high mortality rates, which have led to mass emigration from the country and ongoing violations of human rights. It is considered the most severe and dramatic crisis ever experienced by a non-war-ridden country in recent times [37]. In response to this dramatic situation, the European Union, the United States and other countries applied individual sanctions against government officials and members of both the military and security forces [38]. On 2 June 2010, Chávez declared the *economic war*, due to increasing shortages of food and basic necessities.

Historical events increasing local balance.

We now analyze the existence of 'peaks' of increment in the local balance of individual countries (see Methods). We observe that such events are more frequent in the XIX and XX centuries, with practically no one in the XXI century. Events with a large increase in the local balance are also scarce, such that we need to merge together major and middle increments of the local balance to detect major historical events. Some of the detected events are illustrated in Fig. 8.

A characteristic feature of historic events increasing local balance is that the majority of the involved countries form clear geopolitical communities,

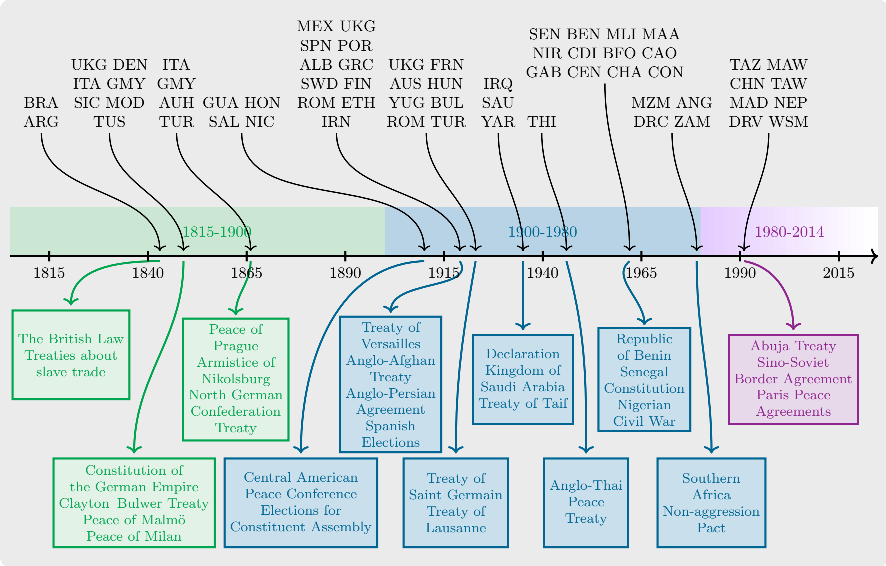


Fig. 8: Timeline of the major events increasing the local balance detected in the XIX-XXI centuries. A table relating each country to its corresponding code is provided in the Supplementary Information.

such as the cases of South American or African countries. These events mainly belong to some of the following cases:

1. Countries becoming independent from their colonial domination;
2. The establishment of treaties, accords or agreements after wars;
3. The implementation of democratic procedures, like elections, change of regime or adoption of constitutions.

The balance of power in South America in the XIX century. One of the historic periods showing significant incremental peaks in the local balance is the XIX century in South America. This was a very convulse period, which started with the independence of several of these regions from the Spanish and Portuguese empires, forming new states. It continues with the fights to balance power in the region. Our analysis revealed that in 1843 the local balance of Brazil increased from 0.58 in the previous year to 0.96, due to the removal of the negative edge of Brazil with Great Britain (maps available in the Supplementary Information). Prior to 1843, Brazil had a clear confrontation towards Great Britain due to the British efforts to suppress the slave traffic [39]. However, in 1843 a new government was formed in Brazil and a number of treaties were signed with Great Britain, as well as with other countries, aimed at suppressing the slave trade [40]. This explains the reduced level of conflict between Brazil and Great Britain and the corresponding increase of Brazil's balance.

On the other hand, a negative edge was created in 1843 between Argentina and Chile, which had confronted interests over Patagonia and the Strait of

Magellan. Argentina's expansion was also seen with preoccupation by the Brazilian government [41]. Argentina drops again its local balance in the years 1845-46 –possibly due to its conflict with France and Great Britain–manifesting the high volatility of the region. The local balance is recovered again in 1847 to $\kappa_i \approx 1$ when the involved countries started to negotiate an end to the hostilities. Brazil followed a similar track due to different causes related to the unbalanced diplomatic situation between Portugal, Great Britain and France. Both Argentina and Brazil had territorial ambitions over Paraguay and Uruguay. Thus, a strategic alliance of Paraguay with Brazil against Argentina helped to increase the former's balance index in the South American network in the transition from 1850 to 1851. A similar strategic alliance with Peru allowed Venezuela to increase its balance from 0.42 in 1858 to 0.88 a year later [42].

The independence of Angola and Mozambique. The most dramatic increase of κ_v observed in this work occurred for Mozambique in 1977 and Angola in 1979. Mozambique had $\kappa_v \approx 0.008$ in 1976 and Angola had $\kappa_v \approx 0.005$ in 1978. They become 0.602 and 0.616, respectively, in 1977 and 1979, respectively. Both the Angolan and the Mozambican civil wars, which began respectively in 1975 and 1977, can be seen as a consequence of the two-bloc structure created during the Cold War (the subgraphs corresponding to both events can be found in the SI). For instance, in the Mozambican conflict that erupted after the country gained independence from Portugal, the Soviet Union aligned with the Mozambican government in 1977, while the US supported the insurgents. More dramatic was the situation after the independence of Angola from Portugal in 1975. A war started between three main players in the country: the *People's Movement for the Liberation of Angola* (MPLA), the *National Union for the Total Independence of Angola* (UNITA) and the *Front for the National Liberation of Angola* (FNLA). On the one side, MPLA was supported by the Soviet Union, Cuba, and Mozambique, while on the other, UNITA and FNLA were mainly supported by the U.S., Zaire and South Africa. In 1978, Angola was a vertex of a balanced square with two positive edges from Soviet Union to both Angola and Mozambique and two negative ones to the same countries from South Africa. In 1979, the Non-Aggression Pact for Southern Africa was signed by the presidents of Angola, Zaire and Zambia. Then, Angola formed a new positive link with Zambia, which makes it take part in two balanced triangles, each having one positive and two negative edges. Angola also formed an unbalanced triangle with Zambia and Congo. This was a long war that extended until 2002 with a large number of casualties, wounded and refugees.

Discussion

It has been claimed that "not everything in history is contingent and particular" [4], but there are regularities that can be revealed with appropriate "coarse-graining" representation and appropriate indices. Here we have used networks of alliances and enmities among countries in the world to reveal major historical events occurring in a relatively long period of history.

We define an index quantifying how much a given country contributes to the global balance of the IR in the world at a given time in history. We use this index to identify major historic events in a "retrodiction"-like analysis, which is claimed as one of the main tools of investigation in cliodynamics [4]. The events identified here could be considered as 'outliers' from the average global trend of IR among countries in the world. But are they 'rare' events? Let us call $p(T)$ to the probability that two significant drops (combined mid or high decrease) of the local balance of at least one country in the world are separated by a time interval T. Then, as detailed in the Supplementary information, $p(T)$ is best fit to the power law $p(T) \sim T^{-2.9}$. This means that while the probability that such events are separated by only 1-2 years is about 70%, it drops to nearly 10% for intervals of 2-3 years and it is almost negligible for separations longer than 5 years. We have found that the main reason why such events occur so frequently is because they are populated by different countries. Indeed, if $p(N)$ is the probability that a given country is involved in N major events dropping the balance in the whole period of 199 years, then $p(N) \sim N^{-1.405}$. This means that the probability that a given country is involved in only one of such events is about 52%, but it drops to less than 20% for being involved in two events in the whole period. The probability that one single country is involved in 10 events in 199 years is only 2%. But history makes exceptions! Chile and Argentina were involved in 15 events, Peru in 16, Brazil in 19 and Spain in 20, mainly due to the convulsive situation existing in South America in the XIX century analyzed before. The analysis of the frequency of events that increase the local balance is given in the Supplementary Information.

Our main goal in this work has been to demonstrate that some coarse-grained representation of IR in combination with an appropriate index can give important historical information of utility for cliodynamics analysis. For this information to be useful in this context we should reconnect it with the main historic and political sciences theories. In the current case, this connection comes from the so-called "balance of power". In this context, Nye [43] has claimed that "*balance of power is a useful predictor of how states will behave; that is, states will align in a manner that will prevent any one state from developing a preponderance of power.*" Therefore, according to Nye "*balance of power predicts that if one state appears to grow too strong, others will ally against it so as to avoid threats to their own independence. This behavior, then, will preserve the structure of the system of states*". On a similar line Weede has expressed that *"limited government and the rule of law are underwritten by balances of power, within and, even more importantly, between states*" [44]. These assertions are based on qualitative geopolitical and historical observations of IR. Can we reconnect them with quantitative theories?

The local balance index captures information about how an individual country reacts to the change of balance of the rest of states in the world at a given time. We have shown here that the information provided by this index can be directly connected to the narrative of major historic events occurring over a period of 199 years. Therefore, the local balance index can be thought of as a quantitative candidate for translating mathematically what historians and political scientists call the "balance of power".

Methods

Data set

The datasets used to construct the signed networks used in this work were collected from [45, 46] for alliances, [47] for enmities, and [48] for strategic rivalries. The coding of inter-country relations is as follows. Two states are assigned a score of +1 at year t if they had any type of alliance (defense pact, offense pact, nonaggression pact, neutrality pact) during that year and zero otherwise. Consultation pacts (see [46]) are excluded. As can be seen, alliance commitments can be asymmetric. The ATOP codes [46] are based on the reading of actual alliance treaties. Some treaties entail asymmetric commitments. For example state i might pledge to help state j if the latter is attacked (this counts as a defense pact), but state j pledges to inform state i of any important military activity (which counts as a consultation pact and is excluded). On the other hand, a dyad is assigned a score of -1 at time t if members had militarized interstate disputes at time t or were considered to be strategic rivals at this time according to the Colaresi et al. [48] data. Therefore, all enmities are symmetric. Since the number of non-bidirectional edges was very small we converted data for each year into an undirected, unweighted, signed network where nodes represent countries and edges their relations in a given year. If two countries happen to be part of both an alliance and a conflict in the same year, we consider the conflict to be dominant, and therefore the edge to be negative. The data describes international relations between countries around the world, over a time range from 1816 to 2014. It includes a total of 221,364 positive relationships and 19,930 negative ones between 217 countries.

Data are thus arranged in a temporal network spanning 199 years with a total of 217 nodes. We emphasize that the number of nodes is far from constant over time, as new states are created and old empires disappear. In fact, the number of nodes typically increases, from a minimum of 23 nodes in 1816 to a maximum of 195 nodes in 2014. The average number of nodes per year is 66. The edge statistics follows a similar trend: it increases from 88 links in 1816 to 8,124 in 2014, with an average number of 1,213 edges per year. On average, 41.22% of the edges are negative, although this number also fluctuates over time: a minimum of 1.49% negative interactions is reached in 2007, while the maximum of 97.30% is observed in 1880. It should also be noted that annual networks are typically not connected and often have many isolated nodes. The giant component represents on average 69.42% of the entire network, with a rather exceptional minimum of 33.33% in 1871 and a maximum of 95.38% in 2011 and 2013. Over the last 50 years, the giant component always exceeds 90%

of the whole network. Since it selects the main actors on the geopolitical scene, the individual local balance values have been computed for such a component only. Plots with the evolution of the different network variables over the time period 1816-2014 are included in the Supplementary Information.

Methodology

To detect whether an abrupt change in the value of a given nation's local balance corresponds to a geopolitical event involving it, we proceeded as follows. For each year t, we extracted the signed adjacency matrix of the network and calculated the local balance $\kappa_v(t)$ for each country v. Afterwards, we aggregated the data from every year, obtaining a time series of the local balance values for each country. Finally, we computed the difference in balance in consecutive years, $\Delta\kappa_v(t) = \kappa_v(t) - \kappa_v(t-1)$, and identified the largest decreases or increases. For balance drops, we identified three categories of events based on the magnitude of the reduction of $\kappa_v(t)$ and we classified candidates into three bands: high if $\Delta\kappa_v(t) \leq -0.5$, medium if $-0.5 < \Delta\kappa_v(t) \leq -0.3$ and low if $-0.3 < \Delta\kappa_v(t) \leq -0.1$. This partition is arbitrarily based on the magnitude of the drops observed for the data and index analyzed. To ensure that this reduction takes place under high imbalance conditions, we filter only those years in which, for a given country, $\kappa_v(t) \leq +0.5$. In order to identify and interpret the most significant positive fluctuations of the local balance index, we applied a similar approach. Specifically, we classified them into three categories according to the value of the positive increase: low for $\Delta\kappa_v(t) \leq 0.1$; medium for $0.1 < \Delta\kappa_v(t) \leq 0.3$, and high for $0.3 < \Delta\kappa_v(t) \leq 0.5$. In all cases, the increase has to bring the local balance of the country above 0.5, that is $\kappa_v(t) \geq +0.5$, and we considered as peaks only values of the balance index that, in a given year, are above that threshold. We also excluded increases due to the creation of a new, previously non-existing, nation or to the entry of a given country into the giant component. By this procedure, we identified events in each band, recorded the corresponding year and country and represented the main ones in a timeline.

References

[1] Maxwell, J. A., & Miller, B. A. Categorizing and connecting strategies in qualitative data analysis. In P. Leavy and S. Hesse-Biber (Eds.), Handbook of emergent methods. New York: Guilford Press, 2008, Chapter 22, pp. 461-476.

[2] Anderson, Margo. Quantitative history. In The Sage Handbook of Social Science Methodology. London: Sage Publications (2007): 246-63.

[3] Gauthier, Laurent. Putting Clio Back in Cliometrics. History and Theory 61.2 (2022): 289-311.

[4] Turchin, P. Arise 'cliodynamics'. Nature, 454 (2008) 34-35.

[5] Kacziba, Péter. The network analysis of international relations: Overview of an emergent methodology. Journal of International Studies 14 (2021) 155-171.

[6] Hafner-Burton, Emilie M., Miles Kahler, and Alexander H. Montgomery. Network analysis for international relations. International organization 63 (2009): 559-592.

[7] Maoz, Z., Terris, L. G., Kuperman, R. D., & Talmud, I. International relations: A network approach. In the book: New directions for international relations: confronting the method-of-analysis problem, Eds. A. Mintz & B. Russett, Lexington Books, Lanham, Maryland, 2005, pp. 35-64.

[8] Maoz, Z. Network Science and International Relations. In the book: Oxford Research Encyclopedia of Politics, Ed. William R. Thompson, Oxford University Press, 2017

[9] Doreian, P., Mrvar, A. Structural balance and signed international relations. Journal of Social Structure 16 (2015) 1-49.

[10] Maoz, Z., Terris, L. G., Kuperman, R. D., & Talmud, I. What is the enemy of my enemy? Causes and consequences of imbalanced international relations, 1816–2001. The Journal of Politics, 69 (2007) 100-115.

[11] Burghardt, K., & Maoz, Z. Dyadic imbalance in networks. Journal of Complex Networks, 8 (2020) cnaa001.

[12] Estrada, E., and Benzi, M. Walk-based measure of balance in signed networks: Detecting lack of balance in social networks. Physical Review E 90.4 (2014): 042802.

[13] Estrada, E. Rethinking structural balance in signed social networks. Discrete Applied Mathematics, 268 (2019) 70-90.

[14] Pattberg, Philipp, and Oscar Widerberg. World politics as a complex system. In the book: Global Networks and European Actors: Navigating and Managing Complexity. Eds. G. Christou & J. Hasselbalch. Rouledge, (2021), pp. 34-50.

[15] F. Heider, Attitudes and Cognitive Organization. The Journal of Psychology, vol. 21, pp. 107–112, Jan. 1946.

[16] Heider, Fritz. The psychology of interpersonal relations. Psychology Press, 2013.

[17] A. Kirkley, G. T. Cantwell, and M. E. J. Newman, Balance in signed networks, Physical Review E, vol. 99, p. 012320, Jan. 2019.

[18] G. Facchetti, G. Iacono, and C. Altafini, Computing global structural balance in large-scale signed social networks, Proceedings of the National Academy of Sciences, vol. 108, pp. 20953–20958, (2011).

[19] D. Escribano, V. Doldan-Martelli, F. J. Lapuente, J. A. Cuesta, and A. Sanchez, Evolution of social relationships between first-year students at middle school: from cliques to circles, Scientific Reports, 11 (2021) 11694.

[20] S. A. Marvel, S. H. Strogatz, and J. M. Kleinberg, Energy Landscape of Social Balance, Physical Review Letters, 103 (2009) 198701.

[21] J. Kunegis, S. Schmidt, A. Lommatzsch, J. Lerner, E. W. De Luca, and S. Albayrak, Spectral Analysis of Signed Graphs for Clustering, Prediction and Visualization, in Proceedings of the 2010 SIAM International Conference on Data Mining (SDM), Proceedings, pp. 559–570, Society for Industrial and Applied Mathematics, Apr. 2010.

[22] E. Ferreira, S. Orbe, J. Ascorbebeitia, B. Alvarez Pereira, and E. Estrada, Loss of structural balance in stock markets, Scientific Reports, 11 (2021) 1-10.

[23] Tamura, Eileen H. Narrative history and theory. History of Education Quarterly 51.2 (2011): 150-157.

[24] Johnson, R. Burke, and Anthony J. Onwuegbuzie. Mixed methods research: A research paradigm whose time has come. Educational researcher 33.7 (2004): 14-26.

[25] Onwuegbuzie, Anthony J., R. Burke Johnson, and Kathleen MT Collins. Call for mixed analysis: A philosophical framework for combining qualitative and quantitative approaches. International journal of multiple research approaches 3.2 (2009): 114-139.

[26] Zaslavsky, T. Signed graphs. Discrete Applied Mathematics 4 (1982) 47-74.

[27] F. Harary, On the notion of balance of a signed graph. Michigan Mathematical Journal, 2 (1953) 143–146.

[28] D. Cartwright and F. Harary, Structural balance: a generalization of Heider's theory. Psychological Review, 63 (1956) 277–293.

[29] Estrada, Ernesto, and Desmond J. Higham. Network properties revealed through matrix functions. SIAM review 52.4 (2010): 696-714.

[30] Podeh, Elie. "Suez in reverse"': The Arab response to the Iraqi bid for Kuwait, 1961-63. Diplomacy and Statecraft 14 (2003) 103-130.

[31] Ashton, Nigel. Kuwait Crisis of 1961. The Encyclopedia of Diplomacy (2018): 1-4.

[32] von Strandmann, H. P. and Evans, R. J. W. (2000). The Revolutions in Europe, 1848-1849: From Reform to Reaction. Oxford University Press.

[33] Hahn, H.J. (2001). The 1848 Revolutions in German-speaking Europe. Longman.

[34] Richmond, D. W. Confrontation and Reconciliation: Mexicans and Spaniards during the Mexican Revolution, 1910-1920. The Americas, 41 (1984) 215–228.

[35] Leffler, J. J. Germany, Mexico, and the United States, 1911-1917. Dissertations and Theses. Paper 3197, (1982).

[36] Adolfo, G. (2006). The Mexican Revolution. New Press; W.W. Norton & Company.

[37] Bull, B., Rosales, A. The crisis in Venezuela: Drivers, transitions, and pathways. European Review of Latin American and Caribbean Studies / Revista Europea de Estudios Latinoamericanos y del Caribe, 109 (2020) 1–20.

[38] Margesson, R., Brown, P., Seelke, C. R., Nelson, R. M. Venezuela: Background and the U.S. Relations. Congressional Research Rervice Reports, (R44841), 2021.

[39] Adams, Jane Elizabeth. The abolition of the Brazilian slave trade. The Journal of Negro History 10.4 (1925): 607-637.

[40] Campbell, Courtney J. Making Abolition Brazilian: British Law and Brazilian Abolitionists in Nineteenth-Century Minas Gerais and Pernambuco. Slavery & Abolition 36.3 (2015): 521-543.

[41] Burr, Robert N. The Balance of Power in Nineteenth-Century South America: An Exploratory Essay. The Hispanic American Historical Review 35.1 (1955): 37-60.

[42] Kroupa, M. Andre. International Trade Relations of Venezuela. Master Thesis (1942). https://ecommons.luc.edu/luc_theses/251

[43] Nye, J. S. The changing nature of world power. Political Science Quarterly 105 (1990) 177-192.

[44] Weede, E. Geopolitics, institutions, and economics. Geopolitics, History, and International Relations 8 (2016) 177-220.

[45] Leeds, B., Ritter, J., Mitchell, S., & Long, A. (2002). Alliance treaty obligations and provisions, 1815-1944. International Interactions, 28(3), 237-260.

[46] Leeds, B. A. (2005). Alliance treaty obligations and provisions (atop) codebook. Rice University, http://atop. rice. edu/home.

[47] Maoz, Z., Johnson, P. L., Kaplan, J., Ogunkoya, F., & Shreve, A. P. (2019). The dyadic militarized interstate disputes (MIDs) dataset version 3.0: Logic, characteristics, and comparisons to alternative datasets. Journal of Conflict Resolution, 63(3), 811-835.

[48] Colaresi, M. P., Rasler, K., & Thompson, W. R. (2008). Strategic rivalries in world politics: Position, space and conflict escalation. Cambridge University Press.

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Data availability. Data for constructing the networks was provided by Prof. Zeev Maoz, who extracted it from the literature previously cited. Request should be addressed to zmaoz@ucdavis.edu

Code availability. The Python scripts used for the data analysis and map generation are available online at https://github.com/fernandodiazdiaz. Additional codes nd information is available from the corresponding author upon request.

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Author contributions. EE designed and supervised the research. The three authors performed the data analysis and created the figures. EE wrote the paper with inputs from PB and FDD. The three authors wrote the Supplementary information. All authors read, edited, and approved the final version of the paper.

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