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The Network of Arms Transfers 1950-2013: An Application of ERGMs and TERGMs

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Abstract

Which factors determine the trade on conventional arms between countries in a longterm perspective? Unfortunately, there are only very few studies investigating these relations quantitatively. The international trade of arms constitutes a network of exporting and of importing countries exhibiting highly complex structures and dynamics. Focusing on the trade on major conventional weapons (MCW) – a sector par excellence for the analysis of political trade deflections – we provide the first statistical network analysis. Based on SIPRI's exhaustive data set we apply cross-sectional and temporal exponential random graph models (ERGMS & TERGMS) to binarized networks. Our preliminary analyses demonstrate that both, economic as well as security consideration are relevant factors with some of them being time specific. Thus, military alliances are losing their imprint at least in the period between 1995-2005, and intrastate conflict continuously attracts weapons imports since 1980. Politico-military considerations seem to regain importance in the last years, thus indicating the emergence of a new international security regime. In order to assess the predictive performance of our model we rely on out-of-sample forecasting.

1 Introduction

There is an extensive literature on international arms trade. However, there are very few positive and quantitative studies providing generalizable insights. The respective trade flows are meanwhile regularly monitored and investigated by the UN, SIPRI, PRIO, as well as by many other think tanks and by several governments. The Stockholm International Peace Research Institute (SIPRI, 2014: 175) estimates military expenditures in 2013 amounting to $1747 billion world-wide. Whereas Western countries reduced their budgets in the aftermath of the global financial crisis in 2007/2008, Asian and African countries experienced enormous increases (SIPRI (2014: 175-182)). In order to measure the volume of international transfers of arms, SIPRI has developed a unique monitoring system. Transfer data are represented as *trend indicator values* (TIV), a measure which is based on production costs. The TIV has the crucial advantage of being consistent over time, which makes it possible to compare the arms flow of different time periods.

Considering the trend in international arms transfers, the decline observed since the early 1980s (1980-1984) turned into a dramatic increase with the beginning of the new millenium, i.e. a ca. 30 percent rise until 2013. SIPRI (2014: 241) indicates 14 per cent growth rates for the period 2009-2013 as compared to the previous five year period, with the US, Russia, Germany, China, France figuring as the top 5 export countries in 2009-2013 (see SIPRI (2014: 258)). Note that China appeared 2012 for the first time in this club replacing the UK in the top five. This position of China reflects a recent important global change in the international arms market - after the collapse of the Soviet Union at the end of the Cold War. It raises questions on the emergence of new alignments and the formation of a completely new system structures.

The world's leading exporters continuously try to maintain and even expand their domestic arms

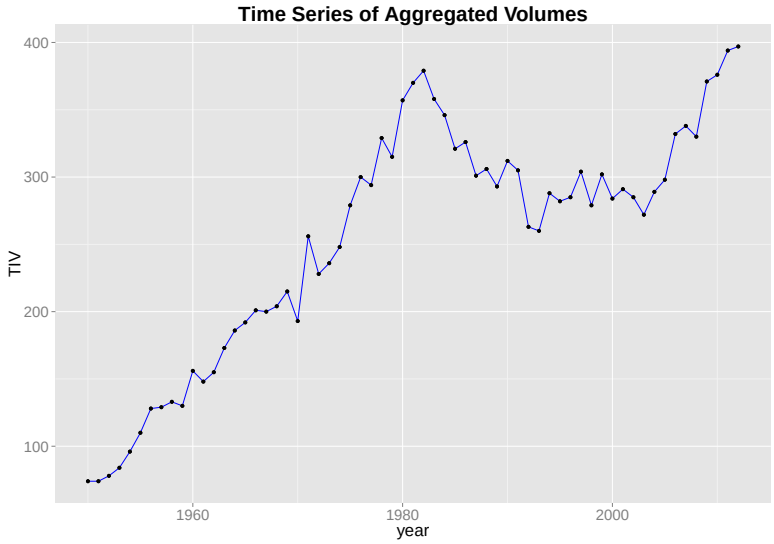


Figure 1: Aggregated trade volumes in million TIV 1950-2013

industries, both in order to ensure their own security as well as for economic reasons. Cuts in military expenditures in the US and the European countries were therefore followed by export promotions and protection of their companies in the arms and military services – just as theories of the economics of arms trade [1] would lead us to expect. The literature, therefore, argues that economic considerations are gaining importance in the decision to supply conventional weapons. But also the demand side compares prices for given arms quality and may choose an cheaper supplier.

In view of these developments, and given the potential destructive consequences of the availaibility of arms, a major research question arises: Who trades conventional arms with whom, and why? Which factors determine trade of conventional arms between countries? More specifically, under which conditions are economic considerations more prevailing as compared to political / security aspects? This amounts to identify, to describe, to explain, and potentially even to predict the structure and the dynamics of the international trade of conventional arms. Given that the international arms trade relations constitutes a complex structure of export and import relations, which should not be reduced to the aggregated transfers of top sellers and buyers, we will argue that a fine-grained network approach is especially fruitful for detecting hidden dynamics and communities. Using disaggregated flow patterns should allow us to discover completely new causal insights with regard to the comparative relevance of security and economic incentives in the trade of such strategic products.

In the following section, we provide a short descriptive overview on the literature on international arms trade. Here we scrutinize especially the existing quantitative literature on arms exports and imports. Section 2 provides our hypotheses derived from the supply-demand template of Levine et al (1994) and from the empirical literature. Section 3 introduces the (temporal) exponential random graph model as an appropriate statistical tool for the explanation of the network structure and its dynamics based on endogenous network dependencies as well as on exogeneous decision criteria. Section 4 presents our results and discusses their implications.

[1] For overviews see Anderton (1995), Garcia-Alonso and Levine (2007), Sandler and Hartley (1995a: chap. 10).

Research on Arms Trade

Surprisingly, the analytical as well as the quantitative literatures on international arms trade, i.e. on the determinants of the structure and of the dynamics of flows of arms between countries are still sparse and spotty. Book-length historical accounts of the development of the international arms trade have been provided, e.g., by Stanley and Pearton (1972), Harkavy (1975), Laurance (1992), Krause (1992), Buzan and Herring (1998). Harkavy (1975) and Laurance (1992) take a systemic approach according to which the evolution of the structure of the international system in a given period is determining the structure and dynamics of arms transfers, and vice versa. Krause (1992) offers a long durée perspective of the historical nexus between the development of arms technologies and the evolution of the international system. Many studies describe the export of arms to developing countries (see Leiss et al. (1970); Ra'anan et al. (1978); Rattinger (1978); Brzoska and Ohlson (1987); Grimmet and Kerr (2012)). Brauer and Dunne (2004) investigate the impact of arms trade on economic development, with a special focus on arms trade offsets. There are also numerous case studies on specific countries, e.g. on the USSR (Porter (1984)), on France (Kolodziej (1987)) and on China (Gill (1992); Gill and Taeho (1995)). The literature distinguiushes different types of actors: Exporting and importing countries, governments, arms producing companies. They all have different motives and objectives, partly being opposite even within the same country. The strategic interaction between these actors differs over time periods and in accordance with the respective structure of the international system. E.g., the Cold War period was characterized by a bipolar alliance structure. Arms exports were mainly designated to allies thus contributing to the production of the public good of joint military capability and interoperability of weapon systems and military services. During the Cold War, we observe a quasi-fusion of governments and arms producing companies. Countries had to trade-off the benefits and cost of a defense industrial base (see Todd (1988)). After the end of the Cold War, these firms became more and more autonomous, and they had to partly define their own market strategies (Inbar and Zilberfarb (1998); Bitzinger (2009)). Regulation policies, industrial policies, and export control policies had to be re-balanced in order to secure the survival of domestic companies in an increasingly globalizing sector. Another major change is the emergence of the supply by non-high income countries as e.g. by Brazil and China. Finally, the supply of and demand for small arms and light weapons (SALW) has gained a new quality. The respective market structure changed from a bipolar structure to a complete fragmentation.[2]

Complaints (see already Anderton (1995)) about the 'non-cumulative' and the often non-positive (i.e. normative) nature of the respective field of research accentuated especially the a) absence of (formal economic) theory-building, b) the lack of data, c) the paucity of empirical analyses. Though our knowledge is still scant and fragmented, the situation has improved considerably in many aspects in the last decade. Extensive and reliable data sets are now available (see Kinsella (2011)). Second, theory-building has made advances. Third, sophisticated quantitative analyses for at least several aspects of arms exports and imports become more frequent. In order to get an impression about the scientific development, we provide a selective overview in the following. First, we describe the structure of formal politico-economic models. Second, we present existing quantitative studies. A major focus will be here on network analyses for the modelling of arms trade flows.

Early formal models of arms production and transfers were mainly politically oriented, i.e. they focused especially on security perceptions and on the resulting arms races between pairs of countries

[2]For recent overviews on the broader context of military production, expenditures, and of exports and imports, see e.g. Brauer (2007); Garcia-Alonso and Levine (2007); Kinsella (2011).

or between pairs of allied blocs (see the now classic studies by Richardson et al. (1960); Olson and Zeckhauser (1966), see also Rattinger (1975, 1976), Gleditsch and Njolstad (1990) and Weede (1995)). Against the background of the end of the Cold War, Anderton (1995) indicated the need to bring in formal economic models capturing explicitly also the economic considerations of the actors involved. Based on clear-cut assumptions, formal models were supposed to derive (ideally: counterintuitive) hypotheses which could then be tested empirically. The most exhaustive respective overview has been presented in the review article of Garcia-Alonso and Levine (2007: see especially pp. 957- 967) and by Brauer (2007). Very often this literature refers to and builds on the Levine et al. (1994) model assuming a supply and demand model of oligopolistic competition. For the formal representation of oligopoly with few sellers and many suppliers, we rely on ??Garcia-Alonso and Levine (2007)). Assuming two different types of countries, suppliers are denoted by $s = 1, 2, ..., l$, and buyers by $b = 1, 2, ..., r$. Only few countries dispose of companies being in the position to produce competititve weapons for which there is an international demand. Many countries are facing local and regional conflicts and, therefore, strive toward advanced arms technologies. The welfare function of importing countries maximizes the following multi-period function U_{bt} with t indexing time:

$$U_{bt} = \sum_{i=0}^{\infty}(1 + r_b)^{-i}W(C_{b,t+1}, S_{b,t+1}),$$

with $W(\cdot)$ representing the utility from single-period utility function including security, S, and consumption, C, with rb as the discounting factor. Security is depending on local hostile countries (characterized by the asterisk) and determined by their military capabilities, i.e. their stock of arms as well as by the own capabilities K:

$$S_{bt} = S(K_{bt}, K^*_{bt})$$

The stock of arms can be partitioned into imported, M_b, and domestically produced weapons, D_b, as well the depreciation of the previous buildups:

$$K_{bt} = f(D_{bt}, M_{bt}) + (1 - \delta)K_{b,t-1}.$$

where $f(D_{bt}, M_{bt})$ represents the respective mix of domestically produced and imported weapons. The budget constraint can be written as:

$$Y_{bt} = C_{bt} + p_{bt}D_{bt} + P_tM_{bt}$$

with Y_{bt} being the total output in t, with p_{bt} and P_t indicating the unit costs for domestically produced and for imported arms. This allows to determine the participation decision of the domestic firm.

Supply countries maximize the following welfare function:

$$U_{st} = \sum_{i=0}^{\infty}(1 + r_s)^{-1}W(C_{s,t+i}, S_{s,t+i})$$

Per assumption, exporting countries take into account world-wide externalities of arms stocks:

$$S_{st} = S(..., K_{bt}, K^*_{bt}, ...; ...K_{st}, ...).$$

with $b = 1, 2, ..., r$ denoting the the stocks of each pair of buyers, and $s = 1, 2, ..., l$) and each of the suppliers including the focal country.
Note, that exporting countries also import weapons, and their stock is

$$K_{st} = f(D_{st}, M_{st}) + (1 - \delta)K_{s,t-1}.$$

Assuming balanced trade conditions, the exporter's budget constraint is

$$Y_{st} = C_{st} + p_{st}D_{st} + P_t M_{st}$$

Export countries are assumed to decide the volume of exports, X_{st} and to set the domestic price of arms p_{st}. This guarantees a domestic production capability for given domestic and external demand and costs.
In sum, supply countries optimize two main criteria: a) minimizing the effects of negative externalities due to the provision of arms (political, security criterion of the welfare function), and b) maximizing the economic returns. As a rule this implies a non-trivial trade-off for decision-makers. The calculus of the export decision also includes domestic aspects, like the technological adavance of companies, their labour market potential, as well as stock-building for own security reasons. The selling country's import decision is primarily based on conflict perceptions (political, security criterion), and it involves the consideration whether to buy or to produce, and given the side constraint of the budget restriction.
This stylized model assumes two (types of) players (few sellers, many buyers) optimizing over several periods, and it solves for prices and amounts of traded arms in equilibrium. Whereas it constitutes an insightful template which can inspire the empirical analysis of different contexts and periods, it is, naturally, analytically intractacable for more complex settings. More specifically, it assumes the pre-existence of an oligopoly, but does not try to explain the dynamic emergence of the observed pattern of accumulation and of the structuration of the international field of security and of economic interdependencies. Anderton (1995) already highlighted the respective promising potential of New Trade Theory (Krugman and Obstfeld (1994)) with its focus on imperfect markets. Contrary to the established standard models of comparative advantage at that time, this new approach is much closer to reality: It focuses on path-dependencies where lead-countries are effective in maintaining and strengthening their military sectors' technological advances; economies of scale lead to decreasing relative costs of production; and so-called network effects facilitate military cooperation the higher the diffusion of identical product standards. However, so far, existing formal models do not explicitly include these insights into their models, nor do they really represent the evolution of the market structure and of network dynamics. [3] A series of other shortcomings of the standard supply-demand model become especially obvious when considering the Helpman et al. (2008) approach and it's critique of gravity models of trade: e.g., there are receiver and sender-specific variations to be captured, and there might be an interdependence between the decision to trade at all with the decision to trade specific amounts. Finally, conflict dynamics are out of sight of the standard model by Levine et al. (1994). A useful theoretical starting point is the new strategic, game theory oriented literature where armement decisions (militarization) are endogenized by assuming anticipation of conflict onset and the exercise of violence (see Powell (1993), Meirowitz and Sartori (2008), Jackson and Morelli (2009)). These games are built for more complex settings than the original Richardson arms race model.

[3] For the general literature on networked markets see Jackson (2008) and Jackson (2011), for an explicit model on network dynamics see e.g. Steglich et al. (2010); Snijders and Steglich (2015).

Quantitative Literature

In the following we provide a short discussion of the quantitative literature focusing exclusively on exports and/or imports as explananda. Note that our list of discussed contributions is to our knowledge: exhaustive. The small number of contributions, therefore, indicates that this important topic is clearly underresearched. The literature starts in the late 1980s according to our search. It is mostly divided into export-oriented studies on the one hand and import-oriented studies on the other hand.

There are several articles focusing on the export of arms (Blanton (2000, 2005); Moore (2010); Perkins and Neumayer (2010); Comola (2012)). Blanton (2000) is interested in whether the human rights situation and the degree of democracy in a receiver country determine the export of arms by the US in the period 1990-1994. Blanton (2005) covers the longer period 1981-2002. In both articles she uses a Heckman model for the two-stage decision of delivering (0/1) and of which amount. In her first article, she finds that "[...]that in the initial decision- making stage, human rights and democracy are important determinants of the eligibility of countries to receive arms. In the second stage, democracy is significant, though human rights no longer affect the decision on the amount of arms to be transferred" (Blanton, 2000: 123). In the second paper it turns out that during the Cold War period, human rights violations in importer countries did not deflect transfers. In the post-Cold War period, the acceptance of human rights and the existence of a democracy in the receiver country increased the probability to be eligible for US arms. Data base for the dependent variables are in both articles the arms transfer data of US Department of Defense Security Assistance Agency as well all export agreements of USA with developing countries. The author uses a series of plausible control variables like GDP, population size, and conflict in the receiver country. Kinsella (2002) investigates the arms transfer competition of the super powers from 1951 to 1995 towards the Third World. Using cointegration and error correction techniques, he is able to corrobarate the idea that transfer dynamics have been correlated and induced by the demand for military-technological innovation. The analysis relies on SIPRI data. Moore (2010) investigates the determinants of the violation of UN embargoes in the period 1978-2002 based on SIPRI data. Only dyads that had already a history of trade are used in the first stage. The author is able to corroborate his main hypotheses according to which violations of embargoes are more probable the higher the dependence of the importer from the violator (first stage) and according to which the traded amount is the higher the more politically similar states are. Dynamics are taken into account by one year-lagged independent variables in the first stage model and additionally by specifying cubic polynomials for time in the second stage. Perkins and Neumayer (2010) compare export decisions and delivered amounts to developing countries for GB, France, Germany and the USA over the period 1992-2004. Based on SIPRI data they find that these countries actually do not discriminate against authoritarian regimes and human rights abusing countries. Economic and security interest prevail over these values. Erickson (2013) assesses the impact of arms embargoes on exports for the period 1981 - 2004, both for MCW and for SALW based on arms transfer data for the 22 top exporting countries to 189 importing countries. Based on a very extensive list of all types of embargoes, the author comes to a different conclusion as compared to Moore (2010): Embargos seem to effectively reduce the violations by senders. Relying on SIPRI data Comola (2012) tests for the period 1975 - 2004, and for the selection of top 20 exporters whether right wing governments export to a higher degree MCWs as compared to leftist govenments. Using a gravity model based on a tobit regression with fixed effects she is able to show that right-wing governments actually trade more arms, and in accordance with business cycle models, one year before the end of the legislative period, the amount of exported arms decreases.

What are the causes of and preconditions for arms imports? The quantitative literature focusing exclusively on import comprises to our knowledge only 4-5 articles (Pearson (1989); Smith and Tasiran (2005, 2010); Childs (2012)). These papers identify the existence of threat perceptions, local arms races, the non-existence of a domestic industry etc. as important drivers. However, the decision to buy is also influenced by a countries' welfare and prices as has been shown in the literature (see e.g. Brzoska (2004)). Pearson (1989) is one of the first studies explaining world-wide imports for the periods of the 1977 - 1980 und 1981 -1983 respectively. The selection of these periods remains unclear. Data base is the Arms Control and Disarmament Agency (ACDA). The author uses simple regression models showing military expenditures to have the highest impact on imports. As Smith and Tasiran (2010) avoids the selection bias problem of Smith and Tasiran (2005), we only describe the former. It covers the period 1981-1999 and includes now all countries world-wide. The paper aims to identify the import elasticities of SIPRI based MCW imports with regard to prices, i.e. with regard to the ratio of the ACDA financial value to the SIPRI-TIV measure. The authors expect a nonlinear demand function where growth in income and military expenditure should cause the import probability to rise and then to fall due to the development of a domestic arms industry to develop. This holds for cross-sectional analyses, but disappears when using a random coefficients models. Thus, random effects are interpreted as capturing the non-linear expected effect. Childs (2012) provides a similar approach as Smith and Tasiran (2010), but his dynamic panel regression includes 187 states, considers the period 1950-2011, and uses exclusively SIPRI data. The model includes GDP per capita and military personal. Though these separate studies on export and imports relations are highly instructive, we are urgently in need of empirical research designs which allow to combine these partial models within a joint model where trade, i.e. exports and imports, is combined in one and the same model, and where those variables discussed in the literature are used in combination. We propose to apply innovative research designs taking stock of the available theoretical models and hypotheses and to implement them for joint empirical tests. The advantage will be to be able to identify endogenous network processes and at the same time to account for hypotheses related to the characteristics of the countries (e.g. node characteristics like military expenditures, regime type, human rights index etc.) and for hypotheses focusing on relational aspects between dyads (e.g. regime similarity, joint memberships in IGOs and alliances). To the best of our knowledge, there are only 2-3 network studies on international arms trade, only two of them being meanwhile published:

1. **Kinsella (2006): The Black Market in Small Arms: Examining a Social Network. *Contemporary Security Policy 27* (1), 100-117.**
   The author proposes a research design for the identification of black markets in SALW. Using the Black Market File Archives provided by the Norwegian Initiative on Small Arms Transfers (NISAT), he dissects the documented events into a relation between suppliers, intermediaries and recipients. He investigates the period from 1990-2002, focusing exclusively on African countries as recipients. It is argued that black markets reveal hidden social networks rather than price-related market transfers as in the case of SALW. Major results are, that there is a clear market differentiation with regard to supply, transfer and recipient countries. These statements are based on centrality measures. This is the first publication on arms trade networks considering supradyadic relations.

2. **Akerman and Seim (2014): Akerman, Anders/Seim, Anna (2014): The global arms trade network 1950-2007, Journal of Comparative Economics, 42, 535-51.**
   Despite the title alluding to networks, this study applies an econometric gravity model in order to explain the binary decision whether a country trades arms with another country. The authors rely on SIPRI data. A major effort is directed to test whether arms trade during the Cold war period reflects the similarity of regime types. Actually, this expectation can be corroborated for the period of the Cold War, but not so for later periods. The descriptive part of the paper uses network visualization. The analytic, explanatory part is restricted to dyadic relations only. For the specification of the gravity

model the authors specify a linear probability model, i.e. they explain dichotomized trade flows with OLS regression.

3. **Willardson (2013): Under the influence of arms: the foreign policy causes and consequences of arms transfers. PhD diss., University of Iowa.**
This is the first network analysis using explanatory statistical and inferential analyses. The author argues that the emerging, supradyadic network properties of dyadic relations may exhibit their own impact on trading. In one of the chapters of his dissertation (p. 78-101), he uses the extensive SIPRI database on conventional arms, distinguishing 6 decades (1950-59, 1960-69, ..., 2000-09), where all transfers within a dyad are aggregated. The resulting valued relation is binarized. For the explanation of the occurrence of ties, he uses static Exponential Random Graph Models (ERGM) for each of the six decades. With regard to network characteristics, he author takes into consideration edges and several triadic relations. The results are counterintuitive: The author finds no impact of alliance membership on arms trade(Willardson (2013: 101)).

In conclusion it can be said that the quantitative literature covers distinct periods, uses different sets of countries and different data for independent and dependent variables, and it proposes diverse hypotheses and controls. Variables are often differently operationalized, and various statistical models are applied. Insofar, the results are still very disparate, fragmented, and only partly comparable. As a consequence, our knowledge is far from being robust. Willardson (2013) is so far the most extensive network study on the topic. It partly contradicts the findings of Akerman and Seim (2014). Those very few studies focusing explicitly on bilateral flows of arms trade are using econometric gravity models. Gravity models are restricted to dyadic relations. Therefore they exclude potentially important hyperdyadic dependencies and processes (see recently Manger et al. (2012); Kinne (2013)). This is the reason why we have to refer to appropriate models of network analysis.

2 Theory and Hypotheses: Linking Arms Trade Theory and Network Analysis

Our discussion of the state of the art has shown, that currently, quantitative research on arms trade is separated into studies of arms import and arms export. We strongly argue to go beyond by building a truly relational network approach to international trade of arms where system mechanics and governments' domestic factors and decision calculuses are systematically combined.
For the first time we intend to take into account endogenous as well exogenous mechanisms of network formation in this area. Given the supply and demand template by Levine et al. (1994) and the claims of New Trade Theory, we will consider node (country) attributes, both from senders and recipients (e.g. GDP, military capabilities, domestic conflict), relational attributes (e.g. alliances, regime similarity), and network structures and processes (preferential attachment/cumulative, hierarchies, triadic closure, higher-order triadic embeddedness, etc.) as potential causal factors .
The quantitative literature on arms trade has offered a series of interesting and plausible hypotheses on which we will also build. Additional to the existing literature, we will also explore whether for some of these hypotheses there are differential sender and receiver-specific effects. In reliance with observed evidence, we expect that many of our hypothesized effects change over time as the observed fragmentation in the arms trade network increases (see Sandler and Hartley (1995b); Akerman and Seim (2014: 251)) and new security structures emerge.
A first parsimonious explanatory model should capture essential economic and political factors - as included in the standard supply and demand model by Levine et al (1994) - in order to assess the trade-off between economic and political factors in a given year or period. With regard to the economic considerations of governments we propose to conceive gross domestic product per

inhabitant as the main decision criterion. Governments are assumed to maximize the welfare of their population. The military sector contributes directly as well as indirectly via R&D investments to the welfare of a country. Military-technologically advanced countries, therefore, support the export of their domestic companies' weapons. At the same time they have to assess whether the trading partners are solvent and financially sound. Economically powerful countries invest into their military security in order to secure their own domestic survival and the status quo of international exchanges, or even expand it against the will of other countries. In case where they can't develop these technologies themselves, they are required to import. Insofar we should expect imports from economically strong countries to economically relatively strong countries (see Blanton (2000, 2005); Perkins and Neumayer (2010); Comola (2012)).

Hypothesis 1: The larger the economic welfare of a country, the higher, ceteris paribus, the probability of arms trade between countries.

The decision to procur weapons for the armament of a country requires ressources and is reflected in its military expenditures (see Blanton (2000); Moore (2010)). However, we suggest to rely on a more encompassing concept of ressources including fungible assets and capabilities. The Composite Index of National Capability (CINC) is an integrative measure reflecting the availability of generalized internationally relevent capabilities. It combines quantifiable measures for (urban) population, steel production, military expenditures and personel, and energy consumption into one index. We expect that the higher the level of such capabilities the higher on the hand the probability that a country exports, on the other hand, such countries continuously intend to secure or increase their capabilities by steadily importing conventional weapons.

Hypothesis 2: The higher the endowment with various capabilities, the higher the probability of supplying, and the higher the probability of importing conventional weapons.

The trade in arms is not a purely economic transaction, but also a political and security-related exchange. Like most markets, the resulting system of bilateral exchanges does not constitute a perfect market in the Walrasian and Debreu sense, i.e. with many anonymous sellers and buyers being price-takers. Rather, it is a highly (pre-)structured, networked market (Jackson (2008); Kinsella (2006)) exhibiting special dynamics (graduality, acceleration) or stability in different periods and spaces. Market deflections in MCW sector are created by political considerations. We distinguish two main political decision criteria in the governmental calculus, namely being connected through military alliances (see Cranmer et al. (2012)) and the existence of common political values as indicated by the regime of a country.
Following the fully-fledged approach of Networked International Politics (NIP) by Maoz (2011), the structuration of arms transactions can be considerd to originate from the so-called security-related egonets (see Maoz (2011: 109-146)) of countries. Here, the core concept of a strategic reference group (SRG) is the driving force for relational dynamics of cooperation and conflict. Any country with which a focal country anticipates a future conflict, and even if this is only because the country is the friend of an enemy, has to be considered a potential security challenge. Therefore, each focal country considers the alliance portfolios of partners as well as the one of challengers. Decisions to trade security and non-security related products mirror these considerations and the intention to minimize negative externalities when trading arms. Thus, there emerges a multiplex network of alliances and of the flows of strategically important goods, both enforcing each other, but also

entraining the trade of non-strategic goods. Maoz derives numerous interesting hypotheses[4] with regard to countries micro-decisions, system dynamics and emerging macro-outcomes. E.g., states are expected to ally with states that are enemies of members of their SRGs. This should gradually give rise to cliques converging finally to a global bipolar structure. On the other hand, there are tendencies eroding the dynamics toward bipolarization, as expected by liberal theories, and to be observed in reality already since the 1960s and 1970s. It is of interest when and how the alliance/arms trade overlap was hollowed out. This model, therefore generalizes the aspect of negative externalities of the two-player supply and demand model of Levine et al. (1994) for the set of all countries. The emerging overall market structure reflects such security considerations. It represents direct and also indirect trust relations between trading partners (see Jackson (2008: 331)). Surprisingly, to our knowledge, only Perkins and Neumayer (2010) and Willardson (2013) discuss similar arguments. The latter finds no impact of alliances on arms trade, whereas the former finds the expected impact for the case of Germany, the US and UK, not so for France (in the first stage of their separate models for the choice of partners and the traded amount respectively).

Hypothesis 3: The pre-existence of military alliances increases the probability of arms transfers between the respective country-dyad.

Trust relations should be also the more probable the more countries are sharing similar political values. The commitment to similar procedures of collective decision-making and the involvement of civil society relates to the risk of abrupt policy changes. Democracies' commitment to once contracted international agreements is relatively more reliable. Insofar, we expect that countries trade the more weapons the more similar their political regimes are (see also Blanton (2000, 2005); Perkins and Neumayer (2010); Comola (2012); Willardson (2013) with quite mixed results).

Hypothesis 4: The higher the extent of shared political values, the higher the probability of observing arms transfers between the respective country-dyad.

Finally, we propose to account for the ambivalent situation of conflict involvement. Conflict involvement of a demand country may sometimes be considered as capturing a negative externality for a country's interest. On the other hand it contains a clear economic pull factor. Given the fact that we already account for political similarity and alliances in our model, we expect that conflict should be an additional economic attractor for arms trades. Exporting countries, ceteris paribus, value especially potential sales quantities, when conflict-involved countries seek for military-technological products. As a rule, demand countries seek for alternative suppliers when other export countries take a restrictive stance due to security reasons.

Hypothesis 5: Conflict within a country, or the involvement of a demand country in an international conflict leads to an increased demand, and thereby to a higher probability of arms imports.

So far, there is no published work relying on statistical network models for the analysis of the emerging hyperdyadic networks in the arms trade sector. It is only with the availability of new methods provided by Snijders (see Snijders (2011); Steglich et al. (2010); Snijders and Steglich (2015)) that we see more recently the application of dynamic network models in the subdiscipline of international relations and international political economy. E.g. Manger et al. (2012) and Kinne (2013) rely on Snijder's so-called stochastic actor based model for the the explanation of

[4]See the synopsis of propositions 177-178 of the realist/liberal and constructivist paradigms.

the formation of preferential trade agreements, and bilateral cooperation agreements, respectively. They are able to show endogenous network processes like the accumulation of ties ('preferential attachment') and triadic closure, with the latter mechanism being interpreted both in terms of economic incentives (Manger et al. (2012)) and to ensure trust and build up social capital (Kinne (2013)).
These new studies provide interesting rationales especially for the occurence and impact of endogenous network processes, which are also relevant for our case. However, in our context we expect an even more pronounced hierarchical market structure for the trade of MCW. This imperfection of the international arms trade market results from the fact that only few countries dispose of the technologies to produce competitive arms systems. Path-dependencies and the asymmetric accumulation of knowledge and of resources lead to economies of scale (see Krugman and Obstfeld (1994: 177 ff)) and to country-specific and company-specific specialization. The accumulation of outdegrees and exported amounts are consistent with New Trade Theory in that some states will excel at producing certain types of weapons (e.g. tanks) and will then export these weapons because of (a) high demand internationally and (b) domestic economies of scale. Such effects are also consistent with the more general process of preferential attachment that Barabási et al. (2000) has proposed as a general property of scale-free networks. In order to secure intertemporal operation of their stocks, importers are depending on one or very few providers.

Hypothesis 6: The arms trade network is characterized by a hierarchical structure, where few countries have many outdegrees (export), and most of the importing countries rely on very few or even only one supplier(s).

As a consequence of the developmental asymmetries we argue that reciprocated arms transfer relations will only occur for those highly developed countries within (alliance) blocs, e.g. the G7, the Warsaw Pact or NATO. I.e., only for these countries we expect intra-sectoral trade. When increasing returns to scale are realized among a few early movers in the development of advanced military technologies, reciprocal differentiated markets emerge. This is the new trade theory / new economic geography prediction for why we observe, for example high arms production in both Germany and the US, but also high levels of arms trade between the two. More fundamentally: reciprocity is the cornerstone of contribution theory and, in repeated games, is the primary mechanism by which cooperation is achieved. So, while there might be independent financial reasons for reciprocal arms trade, there may also be cooperative incentives for it. However, for the global network we do not expect reciprocity in arms trade.

Hypothesis 7: The arms trade network is characterized by a pronounced global a-mutuality.

Finally, we expect substantial global a-transitivity and a tendency against transitive closures in the global arms trade network. This manifests by a dense core of transnational arms trade, which is highly transitive within, but most states are on the periphery of this core, so the global effect is a-transitivity. This hypothesized pattern is consistent with New Trade Theory's and New Economic Geography's prediction that a dense core and international agglomeration emerge because of technical disparities between trading partners, transportation costs, and first mover advantages in the development of economies of scale (where new firms are not able to compete with incumbents).

Hypothesis 8: The arms trade network is characterized by a hierarchical nested network structure where selected supply countries share same demand countries.

3 Statistical Analysis of Networks

Network analysis is a fast growing interdisciplinary research field with contributions coming from e.g. sociology, economics, business studies, political science, physics, computer science and statistics (Brandes and Erlebach, 2005; Jackson, 2008; Easley and Kleinberg, 2010; Newman, 2010).
Kolaczyk (2009) and Lusher et al. (2013) give a first comprehensive collection of statistical contributions in the field. Snijders (2011) provides a survey of recent statistical models for social networks. In the following we introduce an approach for the modeling of asymmetric binary decision to trade. A network of N nodes can be considered as $N \times N$ dimensional matrix Y with entries $y_{ij} = 1$ if nodes i and j are connected by an edge and $y_{ij} = 0$ otherwise. If the edges are undirected we additionally have $y_{ij} = y_{ji}$. First generation models for network data, so called p_1 and p_2 models, start by modeling $P(Y_{ij} = 1)$ explicitly without conditioning on the remaining network structure (see Holland and Leinhardt, 1981)). This leads to standard generalized linear models theory but apparently, the models are somewhat too simplistic since an edge between nodes i and j does not impact the local network of i and j. This deficit has led to the development of exponential random graph models (ERGM), also known as p^* models, see for instance Wasserman and Pattison (1996) or Robins et al. (2007); Lusher et al. (2013). In ERGMs one assumes that network ties are a function of network statistics such that

$$P_\theta(Y = y) = \frac{\exp\{s(y)\theta\}}{\sum_{y^* \in \mathcal{Y}} exp\{s(y^*)\theta\}} \tag{3.1}$$

where $s(y)$ is a vector of network statistics, θ is the parameter of interest and $\mathcal{Y}$ is the set of all possible networks on N nodes. The numerical challenge in (3.1) is the calculation of the normalization $\sum_{y^* \in \mathcal{Y}} exp\{s(y^*)\theta\}$ and hence the estimation of parameter vector θ.
Given that Y has $2^{N(N-1)}$ possible outcomes requires that exact calculation of $\kappa(\theta)$ is a sum over $2^{N(N-1)}$ elements, which is already in the order of $1.5 \cdot 10^{57}$ for a small network with 20 nodes. Therefore, numerical methods based on Markov Chain Monte Carlo (MCMC) routines have been proposed. Snijders (2002) suggests a new MCMC estimation procedures allowing for the specification of sufficient endogenous structural network statistics and exogenous variables. However these models suffer from notorious degeneracy problems. As a corrective Hunter (2007) and Snijders et al. (2006) discuss new specifications of more complex nested dependence configurations. Recently, Caimo and Friel (2011) propose a new MCMC based algorithm to fit ERGMs. The latter as well as many other routines are implemented in R, such as in the `Bergm` package, the `ergm` package or the `RSiena` package (see Hunter et al., 2008 or Kolaczyk and Csádi, 2014).

While ERGMs were originally developed to account for cross-sectionally observed network choices (Snijders, 2002), most recent developments propose dynamic models which allow networks structures to change in time (Snijders et al., 2010; Westveld and Hoff, 2011). Therefore, for a given time period Hanneke et al. (2010) introduced the temporal exponential random graph model (TERGM), which has been extended by ??cite (Cranmer, Desmarais, Inferential Network Analysis with ERGMs, 2011, doi: 10.1093/pan/mpq037).

$$P_\theta(Y^t = y^t \mid Y^{t-1} = y^{t-1}, \ldots, Y^{t-k} = y^{t-k}) = \frac{exp\{s(y^t, y^{t-1}, \ldots, y^{t-k})\theta\}}{\sum_{y^* \in \mathcal{Y}^t} exp\{s(y^*, y^{t-1}, \ldots, y^{t-p})\theta\}} \tag{3.2}$$

Note that the number of nodes and therefore $\mathcal{Y}$ changes over time. The vector of statistics $s(\cdot)$ can include functions of the network at time t just as the general ERG model in 3.1, but also temporal statistics as the stability of an edge, delayed reciprocity etc. Therefore, the realization of time t is conditioned on the previous k realizations. However, the results of the TERGMs presented in this paper do not consider temporal statistics yet, but regard the joint probability of observing the networks between times $t-k$ and t. This is done by taking the product of the probabilities of the individual networks.

$$P_\theta(Y^t = y^t, \ldots, Y^{t-k} = y^{t-k}) = \prod_{i=t-k}^{t} P_\theta(Y^i = y^i) \tag{3.3}$$

Since the estimating of θ via MCMC algorithm is fairly intractable, Desmarais and Cranmer (2012) propose to estimate the parameter vector by maximum pseudo likelihood estimation (MPLE) and show that the MPLE provides a consistent approximation of the MLE. Furthermore, they introduce an bootstrapping technique to approximate standard errors, which results in a computational cheap way to estimate confidence intervals.

The decision about which network statistics are incorporated into the model affects the model significantly. The selection should be the result of a meticulous analysis of the network, since including the wrong statistics can easily cause degeneracy. Additional to network statistics as the number of edges or the number of k-stars in a network, $s(\cdot)$ can also incorporate conventional exogenous covariates. Generally speaking, covariates can be differentiated into two groups: *nodal covariates*, and *edge* or *relational covariates*. Nodal covariates reflect actors's attributes as a nation's GDP or military capabilities, while edge covariates capture other relations between actors in the network. Examples in our case could be covariates which describe whether two nations have a defense agreement or share a common border. Furthermore, one can include so-called *geometrically weighted statistics* as the geometrically weighted out-degree (Gwodegree) into the model, which were first introduced by Hunter and Handcock (2006) enable the inclusion of an statistic's entire distribution into the model. These statistics are adjusted by an additional *decay parameter*.

4 Results

Descriptives

In the following we will rely on SIPRIs time series 1950-2013 on the exchange of major conventional weapons (MCW). Data availability and data quality has so far been a major obstacle for cumulative work in the arms trade area (see e.g. Holtom et al. (2012)). However, as the recent increase in quantitative articles based on the continuous flow data shows, these new data sets are reliable (for this assessment see also Kinsella (2011)). SIPRI provides transfers based on so-called 'Trend-Indicator Values'.[5] When examining the international arms trade data one recognizes that not only countries are involved in the network. In fact, international organizations like the UN and NATO, terrorist groups like Al Quaida, Hamas, Hezbollah and embattled areas like Chechnya, Darfur or even Eastern Ukraine can actively be involved in the network. However, these trade flows are negligible and as a consequence, we decided not to consider them in the following. Furthermore, we have to take into account that some actors did not exist during the whole time period of consideration. At

[5]"The TIV is based on the known unit production costs of a core set of weapons and is intended to represent the transfer of military resources rather than the financial value of the transfer. [...] SIPRI TIV figures do not represent sales prices for arms transfers." (SIPRI 2014: 271-272).

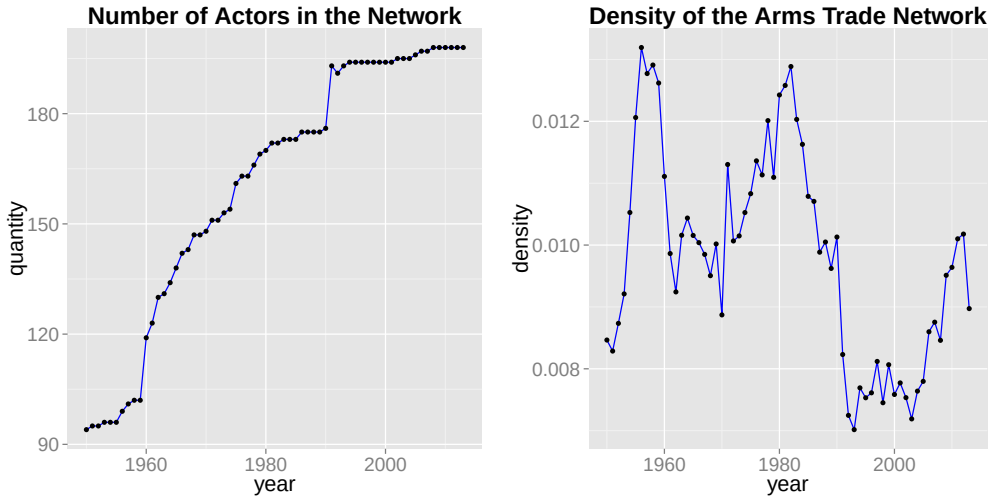


Figure 2: The number of actors included in the arms trade networks (left) and the density of the networks (right) for the time period 1950-2013

one point some countries disappear from the scene, while other countries gain their independence. For each country the observed time periods are presented in the appendix.

The left plot in figure 2 shows the number of actors in the network for each year. There is a conspicuous constant growth of actors from the 1960s until 1980 due to decolonization and the formation of independent sovereign states. A big jump results from the break-up of the Soviet Union in 1990/1991. In the right panel we visualize the time series of the network's density. The density of a network is defined as the number of actual ties in a network divided by the number of possible ties. Here we have to be careful when interpreting the development since the number of actors changes over time. Similarities as compared to the time series of the aggregated traded volumes are evident. Just as in figure (1), we observe a peak in 1982, followed by a decrease until the nineties. Note also, that there is a first peak in the end of 1950s. As the number of countries did not change in the last 15-20 years, it is possible to conclude that the density of the networks rose steadily again in the last years with the exception of 2013.

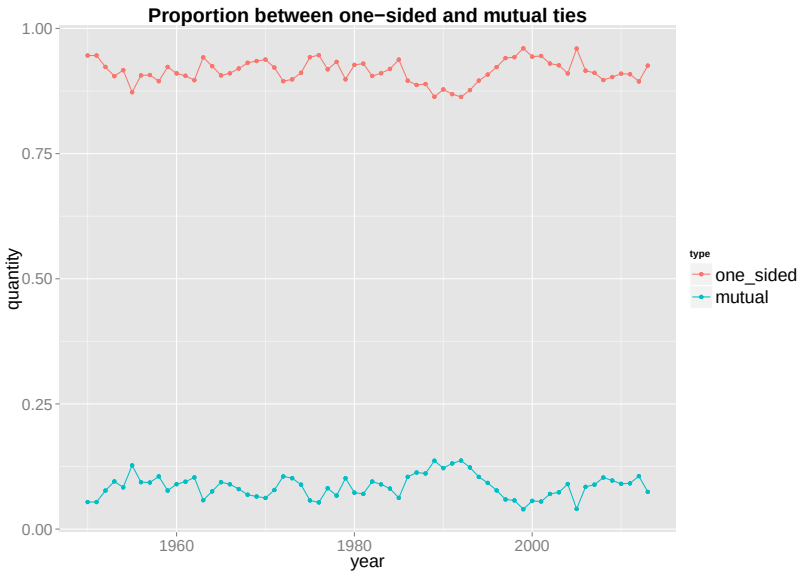
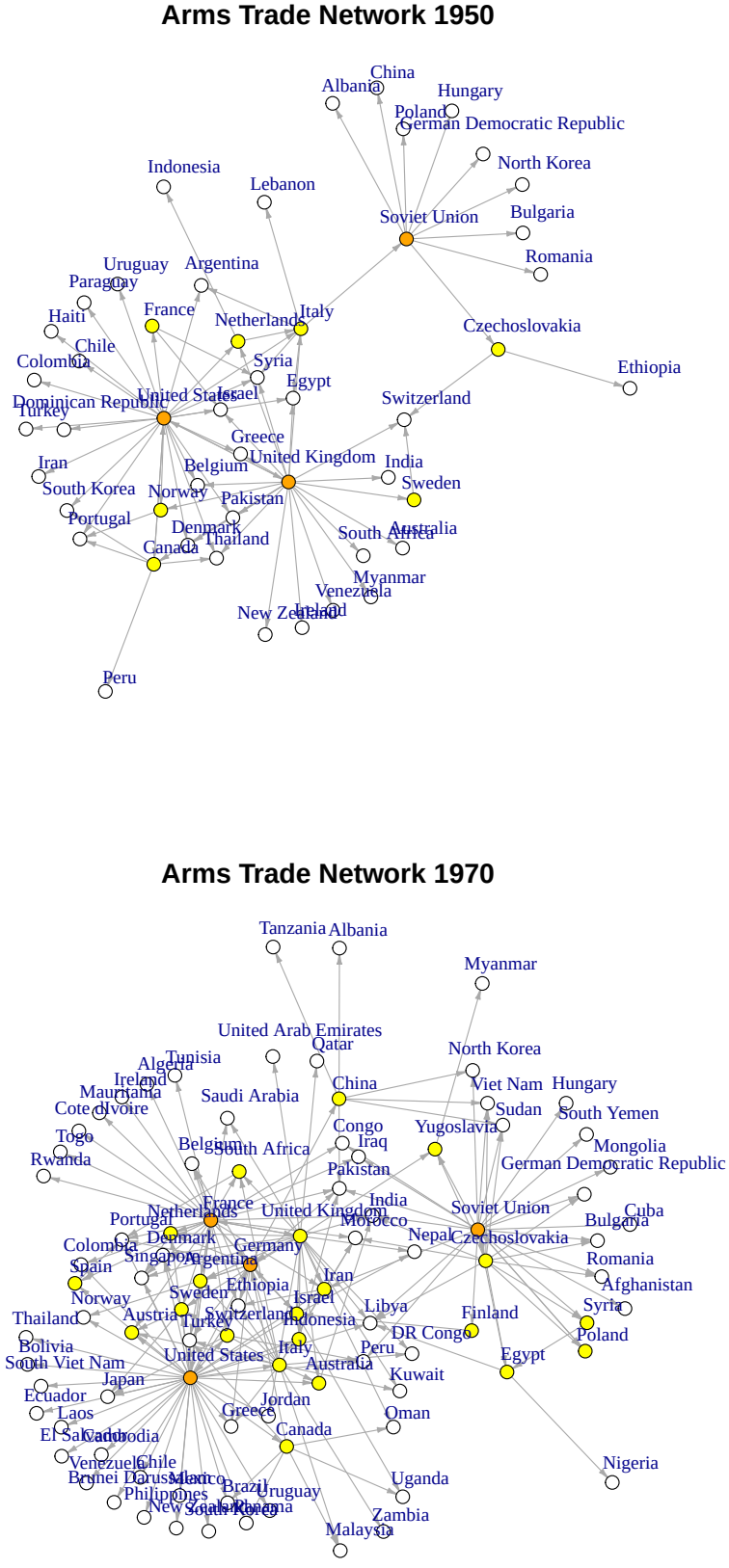


Figure 3: Proportion between one-sided ties (red) to mutual ties (blue) over the time period 1950-2013

Figure 4: The average indegree and out degree distribution for the time period 1950-2013. In each case 90% of the corresponding degree value was situated between the black bars



Data Source SIPRI

Figure 5: The arms trade network for 1950 and 1970. White nodes indicate no out-degree, yellow nodes indicate 0 < out-degree <5, orange nodes indicate out-degree ≥ 5

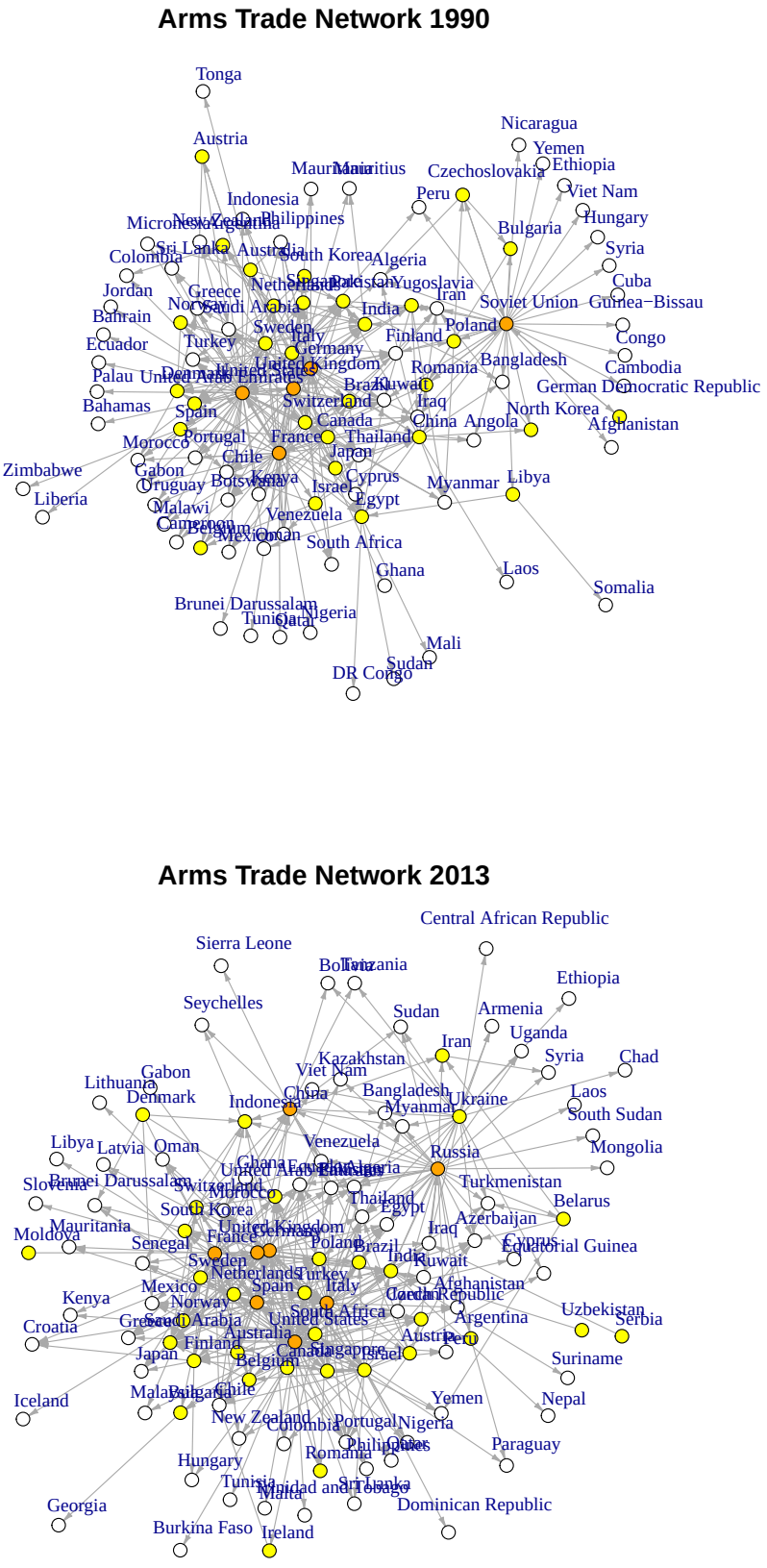


Figure 6: The arms trade network for 1990 and 2013. White nodes indicate no out-degree, yellow nodes indicate 0 < out-degree <5, orange nodes indicate out-degree ≥ 5

An inspection of selected network graphs in figure (5) and (6) demonstrates that the majority of countries, which are actively involved in the arms trade network are only receiving weapons and are not selling their goods to other countries.[6] This leads to star-like patterns with peripherical satellite countries. This insight gets further support by the fact that around 95% of all ties which are not null, are one-sided. The proportion of one-sided to mutual ties is visualized in figure (3).

Figure (4) presents the average in-degree and out-degree distribution for the time period 1950-2013 in percentages. The in-degree of an actor is defined as the number of ties ending at this actor, while the out-degree is defined as the number of ties starting from this actor. Plotting the distribution on a percentage scale enables a comparison of the distributions for different networks with a different number of actors. In each case, 90% of the corresponding degree value is situated between the black bars. The majority of countries are not selling weapons, which can be derived from the fact that over 80% of all actors in the network have an out-degree of zero. On the other hand, more than 40 percent have an in-degree of 0, but this is mainly due to the countries, which are not involved any any weapon trades at all. Note that there is also a high proportion of countries which are only purchasing weapons from one supplier. These countries usually do not sell weapons and are therefore depending on a single supplier.

Operationalization of independent variables

We include the number of edges for the same reason that nearly every linear regression model contains an intercept term. We specify mutuality in order to capture the pronounced asymmetry in the network. Additionally, we include curved versions of the outdegree, and edge-wise shared partners. As our figures on degree-distributions have shown, there are very many countries with few or no out- or indegrees. There are very few countries exhibiting numerous outdeegrees. Most of the countries rely on one single supply country. Insofar we expect a curved leveling of the increase of outdegrees, whereas we expect a indegree (1) parameter to represent the networks best (see figure 4).

The structural statistics of geometrically weighted edge-wise shared partners (GWESP) was introduced by Hunter and Handcock (2006) and is a statistic that geometrically down-weights the parameters of edge-wise shared k-partners (ESP(k)). ESP(k) is defined as the number of connected pairs in the network that are connected over exactly k directed paths of length 2. Figure 7 visualizes ESP(0), ESP(1) and ESP(2). We justify the inclusion of the geometrically weighted GWESP, by the fact that only few (allied) countries (e.g. US and UK) with highly developed military technologies are participating in the intrasectoral trade. Therefore, we expect an overall tendency against transitive closure. However, these countries often export to shared peripherical partners. The number of such shared partners decreases regularly quite rapidly in our network.

For the operationalization of our hypothesis on the impact of alliances we included the *Formal Interstate Alliance Dataset* provided by M. (2004), which is part of the Correlates of War (COW) Project. This data set contains military alliance agreements signed by any nation from 1815 on. We incorporate these data as symmetric adjacency matrices for each year, where a 1 indicates that nations i and j signed a *defense agreement*, while a 0 denotes that the corresponding nations have not.

The second political criterion refers to regime similarity and shared political values. We use data

[6] For the sake of clarity, the countries that did not trade weapons in these years were excluded from the plots.

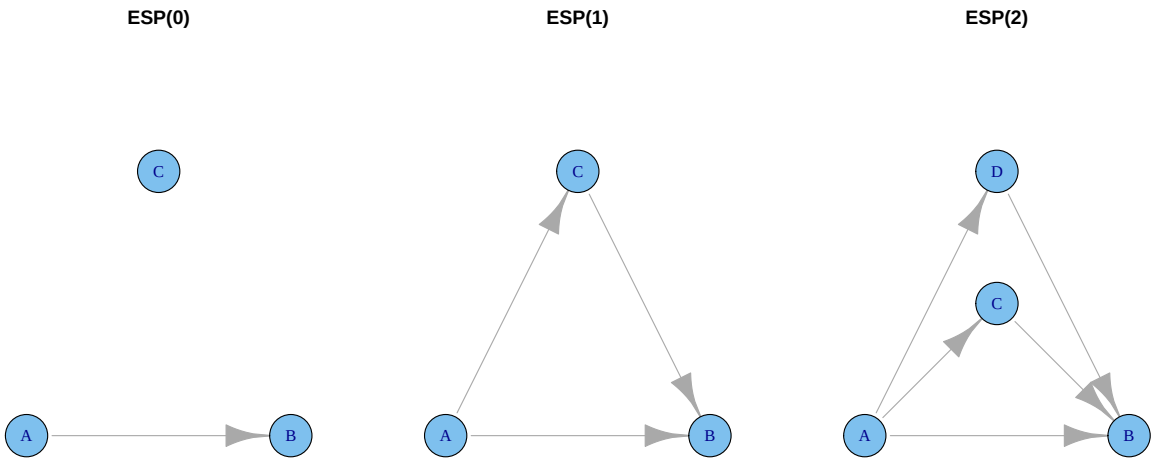


Figure 7: Visualization of ESP(0), ESP(1) and ESP(2)

from the *Polity IV Project*, which is provided by the *Center for Systemic Peace* (CSP) (Marshall (2014)). This data assigns a *democracy score* between 10 and -10 to each nation on an annual basis, depending on its democratic status. A 10 indicates that nation i has the highest democracy standards while a -10 means the opposite. We created a weighted adjacency matrix with the absolute difference in democracy score between nations i and j as entries and include it as a relational covariate.

For the specification of economic power and encompassing capabilities we decided to use GDP per capita and the Composite Index of National Capability. The data on the countries' *gross domestic product* (GDP) per capita in US dollars are based on the Maddison-Project (2013). The Maddison Project is, to our knowledge, the only dataset that also covers socialist and communist countries from before 1990. In order to make the data more accessible for the networks, we shrink the given numbers by taking the natural logarithm. We are going to investigate the GDP as a receiver's and a supplier's effect because we argued that export-oriented countries are those from the highest development level, whereas demand countries should be as a rule from lower development level.

The *Composite Index of National Capability* (CINC) is from the *National Material Capabilities Dataset* (Singer et al. (1972)). The CINC is a statistical measure of national power created for the COW project and conceived as nodal attribute. It uses an average of percentages of world totals in six different components, which represent demographic, economic, and military strength. These components are: total population, urban population, iron and steel production, primary energy consumption, military expenditure, and military personnel. As described by Perkins and Neumayer (2010) we include this data curvilinearly (CINC^2+ CINC) and investigate the data for the receiver's as well as for the supplier's effect.

The next covariate in our model gathers information about inter- and intra-state conflicts and

includes all episodes of international, civil, ethnic, communal, and genocidal violence and warfare. The data come from the *Major Episodes of Political Violance Project* and are also provided by the CSP (Marshall (2014)). The conflicts are coded on a scale of one to ten according to an assessment of the full impact of their violence on the societies that directly experienced their effects. We distinguish between inter- and intra-state conflicts, but incoporate only intra-state conflict as covariate, due to the small number of interstate conflicts.

The covariates defense agreement, and the polity score differences are captured as relational covariates. we include the nodal covariates GDP, CINC and intra-state conflict into the network. The covariates GDP and CINC are incorporated for the supplier as well as for the recipient, while the intra-state and inter-state conflict data are only added for the recipient. As a control variable we include path dependency. This covariate sums up the total TIV sold from country i to country j the five years before the year of consideration. Relational covariates can be presented as a matrix of the same dimensions as the arms trade adjacency matrix. For every existing edge, this statistics add up the associated entries of the covariate matrix. We follow Perkins and Neumayer (2010) arguing that there is a time delay between the order date of arms and the delivery date, which, according to our calculations, turns out to be an average of two years. Therefore, all covariates are included with a two year lag, i.e. for the network of year t we use the covariates of year $t-2$.

Just as Akerman and Seim (2013) we are going to set $a_{ijt} = 1$ if country i sells weapons to country j in year t and $a_{ijt} = 0$ if country i does not sell weapons to country j in yeat t.

ERGM

First, we will use the data cross-sectionally and fit a network for time point t leading to parameter estimates θ_t. We will now investigate the performance of θ_t over t showing how structural relations of trading and/or volume change. The results can be seen in figures 8 and 9. We visualize the estimated coefficients as a time series of coefficients including the credibility interval. Green dots represent coefficients statistically significant at the 5-percent level, orange means significant at the 10 -percent level, reds points represent statistically insignificant coefficients. Consecutive models are specified identically. However, the number of nodes / countries changes. Insofar, intertemporal comparison of coefficient sizes can only be done with caution. As the set of countries is identical for the last 20 years, for this period a comparative assessment is possible. The negative edges coefficient indicate a rather sparse network as compared to what we would expect given the size of the network of countries. As outlined we expect in general a non-reciprocation of trade due to the pronounced world-wide 'division of labour' in this sector. Additionally, the traditional models of trade à la Ricardo and Heckscher-Ohlin expect only interindustry trade. Thus, in line with Maoz (2010) and New Trade Theory, only for highly developed countries being allied or sharing joint values we expect reciprocation. In order to capture this effect we include additionally the G-7 as a homogenous group. Our idea is that this variable could effectively absorb the flows of intrasectoral exhcange. We see that the mutuality effect is mainly insignificant until the end of the 1990s. The non-significance in the earlier years may indeed be due to a mixture of reciprocation within, e.g. the NATO, and the USSR, and a strong asymmtry otherwise. Our hint that the G-7 might exhibit intrasectoral trade, and thereby absorb selected reciprocation and clustering processes is clearly refuted: the homophily effect (nodematch G7) just as their supply (nodofactor G7) as well as the demand effect are not separating.
Instead of degeneracy-prone simple statistics for hierarchies and triadic closures we use geometrically

weighted coefficients (see Snijders et al. (2006); Hunter (2007)), at least for outdegrees and edge-wise shared partners. The effects of geometrically weighted outdegrees (Gwodegree) are clearly negative: there are very fewer countries trading than trading to many other countries as expected. The freely estimated decay parameters (gwodegree decay) are mostly positive, and are mostly larger than 1 througout the entire time period. This indicates a steep curved decline of the number of such outdegrees, which aligns with the results in figure 4 in the description section. For indegrees representing the number of suppliers we decided to specify the indegree(1) parameter as most of the importing countries rely either on one or two suppliers. This parameter turns toward significance in the 1990s. It is negative during which should not suprise as we have to take into account the many more countries with indegree 0. With regard to clustering and the closure of triangles we have argued that we should see rather the absence of the closure of triangles. Originally, we experimented with the statistics dyadwise-shared partners dsp(0) and edgewise shared partners esp(0). With the statistic dsp(0) we intended to capture the fact that the majority of actors in the network are not connected by a directed two-path through a third actor. We justify this on the basis of the geodesic distance distribution of the networks (see figures 12 and 13), which indicate that there is no directed path between most actors. The reason for this is that most actors do not sell weapons and therefore have an outdegree of zero (see figure 4). Consequently, a directed two-path cannot originate from these actors. With the statistic esp(0) we emphazise the direct trades between two actors, since this statistic counts the number of pairs (i, j) which are directely connected and do not close deals via a third party. Nevertheless, there are periods, where countries exhibiting higher degrees of intrasectoral trade are sharing a small number of import countries, and the esp(0) effect proved to be very often negative over the whole period. This is the reason why in the current version of the model we kept only the geometrically weighted edge wise shared partners and the respective decay parameter. The coefficient is positive, but very often insignificant, except in the period of the 1970s to the mid-1980s, and in the last 10 years. Thus, there are such constellations, where exporters jointly trade with identical importers, but they seem to be time-specific, and they are very rare. This is reflected in the freely estimated decay parameter which is again very much larger than 1. A series of other node attributes and relational variables provide additional interesting insights: Defense agreements are somewhat losening their impact since the late-1990s. We observe a positive, but clearly decreasing effect. Even though we have to be careful with the interpretation of trends in the time series since the number of edges increases over time, we can see that the estimates start becoming statistically insignificant around the turn of the millennium. This bolsters the conjectures that the existence of alliances has played an increasingly minor role in countries' decisions to engage in arms trading. Brzoska ?? Michael Brzoska. The economics of arms imports after the end of the cold war. Defence and Peace Economics, 2004 ?? discusses that back in the 1960s and 1970s weapons were sold mainly to allies in order to bolster desired power dynamics and further personal political interests, while nowadays economic factors play a much more decisive role. Note, however the oscillations in most recent years raise some doubts whether this process is already in a stable equilibrium.

As demonstrated in the literature several times, the influence of the similiarity of political regimes (Democracy Score) seems to increase over time. At least with regard to the pre-1990 period, the effect is more often a relevant predictor. The effect is negative, beceause we specified the distance of the Polity-IV scores.

The results for the direct contiguity data turn out to be statistically insignificant at the 10 percent level for most of our examined timeframe. However, for some scattered years we obtain positive statistically significant results, which might be counterintuitive at first glance since it means that

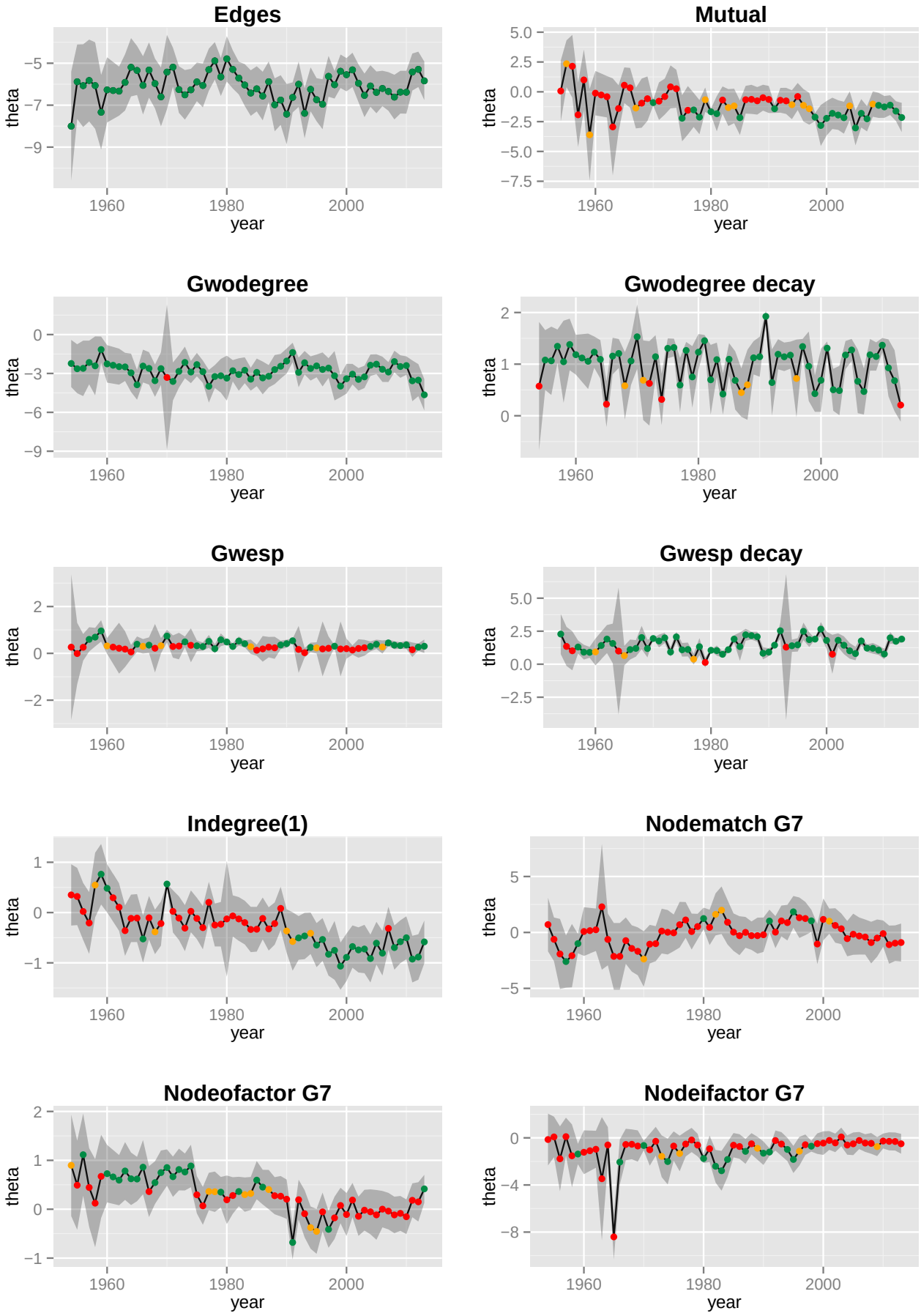


Figure 8: Time series of the estimated ERGM parameters for the time period 1952-2013

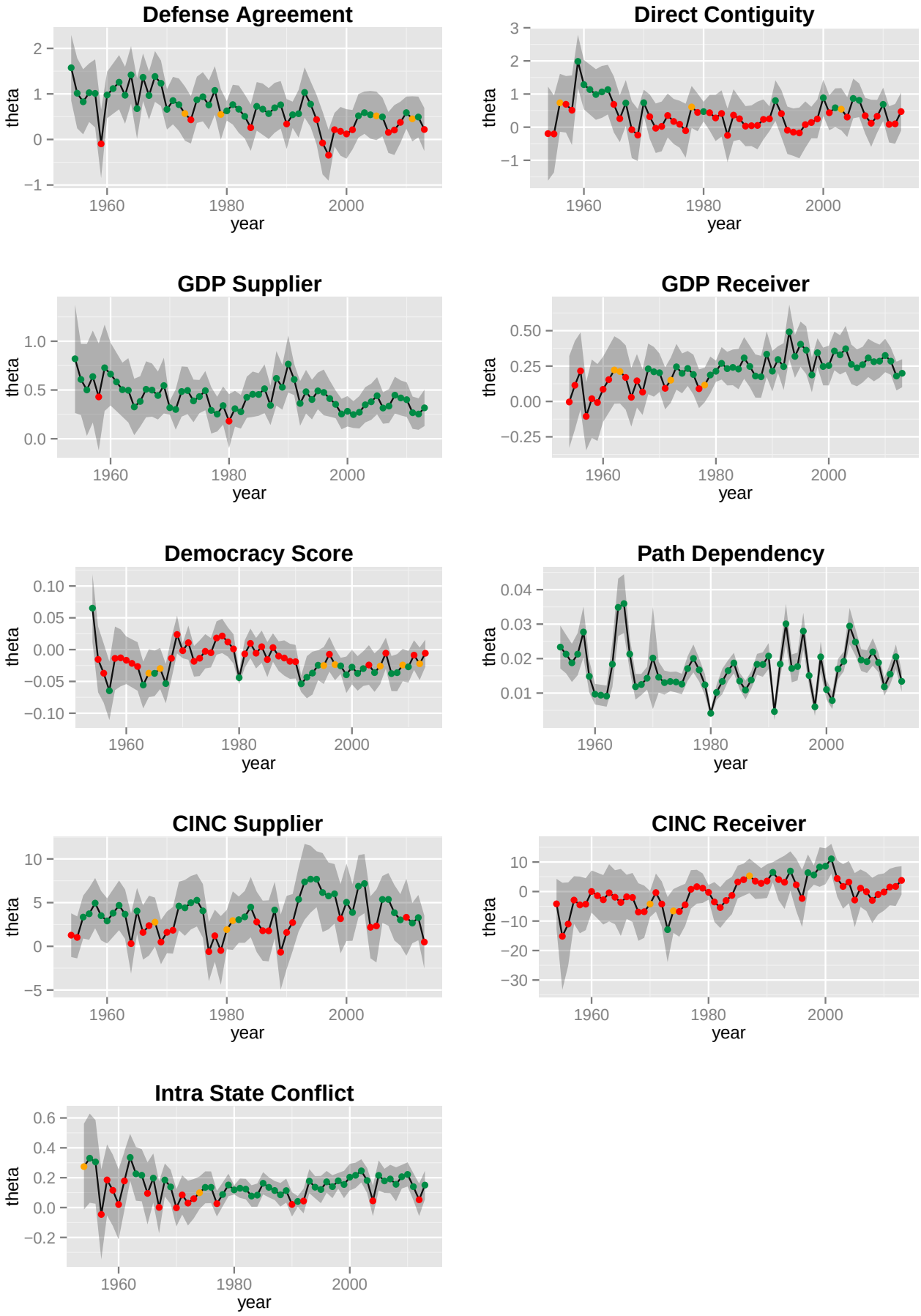


Figure 9: Time series of the estimated ERGM parameters for the time period 1952-2013

countries which share a common border are more likely to trade weapons with each other. A likely reason for this is that the NATO countries in Europe supply each other with military goods.
The higher the GDP pc, the higher the probability that the country is an exporter (GDP supplier). Since the 1980s this holds also for the importing countries. This is another forceful sign that economic considerations have increased over time. For the Composite Index of National Capability (CINC), we see that powerful countries tend to export, notably in order to profit economically and to commit allies. Contrary, powerful states do rather abstain from importing MCWs. Both the receiver's GDP, and CINC estimates bolster Brzoska's conjecture ?? Michael Brzoska. The economics of arms imports after the end of the cold war. Defence and Peace Economics, 2004 ?? that economic factors are increasingly influential drivers in the global armament market.
The time series of the intra-state conflict estimates goes from being highly variable in the early period of our examined time window to demonstrating more consistent estimates from the 1980s on. From this decade on we obtain with some exceptions statistically significant estimates that are positive, which implies that countries characterized by domestic disturbances are indeed more likely to purchase weapons. The Variable Path Dependency captures the inertia of once chosen trading partners: the higher the aggregated amount of MCW in the past the higher clearly the chance to have another deal in a given observed year. This result captures reputation effects, the reliance on once chosen technological standards and the requirement of interoperability in the case of allies.
The goodness of fit of these models is very impressing. As they are of a similar quality as the ones for the TERGMs we refrain from presenting them.

TERGM

In this section we present results of simple TERGMs, i.e simply pooled matrices where in each year we condition on the four previous years. Note that by conditioning on the networks of the previous four years all networks have to be defined on the same nodes. For this reason, we include in the TERGM, of the time period $t-4,\ldots,t$ all countries which did exist at time t. The effects turn our to be similar in their tendency, but smoother and more pronounced. In order to interpret the evolution of the edge parameter correctly, one should keep in mind that we have an increase in the number of countries especially in the 1960s with decolonialization. This is one reason, why the negative parameter decreases until the end of the 1980s, i.e. the network becomes more sparse as expected by the increasing number of nodes. Due to the stability of the number of nodes in the last 20 years, the continous rise of the effect size can be actually interpreted as an expansion of the international arms trade network. There are increasingly more sellers, and to an even higher more buyers. Due to the weighting of the geometrically weighted outdegree distribution (Gwodegree) the overall impact is negative over the whole periods indicating again that in comparison there are very few sellers trading with numerous buyers. As parts of the TERGM currently do not allow to freely estimate the decay parameter we used instead the average of the decays estimated in our ergms, i.e. we fixed the gwodegree decay parameter at 1 and the gwesp decay parameter at 1.5. Notice for the Idegree(1) results that the estimated parameters change from having an insignificant positive effect in the 1950s, to having no effect in the 1960s through the 1980s, to having a significant negative effect in the more recent years. Again the high number of indegree (0) has to be kept in mind.
A-Mutuality can be observed in several periods, i.e. in the 1960s to the mid 1970s, from the 1980 to 1990, and again since the end 1990s. Thus, asymmetry is present most of the time just as we expected for this sector of strategic products. These results have to be interpreted in combination with our conditional homophily expectancy for the G-7: Actually we observe a trend towards trade

within this subset, indicating a sort of conditional intra-sectoral trade. It is unclear whether the pattern in the three last years reflects a tendency back towards less openness in importing and exporting such goods, or whether it is just a reflection of the decrease in military expenditures in Western countries in the last years. More obvious is the clear tendency of G-7 countries to import to a lesser degree, which is a clear sign of self-sufficiency. With regard to the export behavior of this group, it seems that it is too heterogeneous as to identify a clear impact here.
Tendencies for the closure of triangles are present over the whole period. Again, we use the geometrically weighted edge-wise shared partners statistics with a fixed decay parameter. The respective TERGM results is more pronounced.
Defense Agreements are losing their impact from the mid-1990s to around 2005. Then they regain their importance. Thus, loss of relevance seem to be rather a temporary phenomenon. Swan songs on the importance of military alliances seem to be premature. At the same time, economic factors co-exist: For GDP pc, both the probability of supply and demand increases with higher GDP. The pattern for the Composite Index of National Capability (CINC) is again more clear in the TERGM: the propensity to export is higher for larger capabilities until the end of the 1990s. More importantly, since the mid-1980s countries with higher capabilities exhibit higher import probabilities, with the economic crisis leading to a downturn of this impact. Contrary, since the 1990s, import probabilities are the higher the larger the national capabilities. Again, this latter result clearly indicates that economic incentives are present. During the 1980s, regime similarity (Democracy Score) was an influential factor for the trade of arms. Since then, this aspect seem to lose its impact. This applies also clearly to our variable path dependency: the reduction of the respective coefficient from the mid-1990s to the more recent period can be interpreted as decreasing tendency to rely exclusively on previous partners. The occurence of intra-state conflict shows a clear picture in the TERGM: since the 1980s such a constellation is increasingly an important pull factor to import arms.
Both, the ERGM as well as the TERGMs produce interesting results, but the question remains whether our model specification actually supports a reasonable good model fit? For this objective compare the estimated TERG models among others using four hyper-statistics as proposed by Hunter et al. (2008): The in-degree distribution, the out-degree distribution, the geodesic distance distribution between two actors, and the edgewise-shared partner distribution. Whether a model fit is good, can be assessed on the basis of the goodness-of-fit plots presented in figure 12 and 13. After having estimated the vector of parameters θ, we are interested in how similar the distribution of $P_{\hat{\theta}}$ is to the distribution of P_{θ}. Therefore, we are simulating a large number of networks out of the distribution $P_{\hat{\theta}}$ via MCMC and compare the simulated networks based on thedistributions of the hyper-statistics with the originally observed network. The bold black line illustrates the hyper-statistic's distribution of the observed network, while the range bounded by the boxplots displays the range where 95% of the simulated networks' hyper-statistics are located. According to this rationale, a model provides a good fit if the bold black line passes through every single boxplot, and even better if it passes the median. Accordingly, we observe that our model provides a good fit, since the black bold line is passing every single boxplot in every of the four distributions. For other years than the ones visualized in figures 12 and 13 we get quite similar results (results can be provided).

Another way to assess the model fit is given in figure 14 and was proposed by ??cite (Skyler J. Cranmer, Bruce A. Desmarais, and Justin H. Kirkland. Toward a Network Theory of Alliance Formation. International Interactions, 38(3):295-324, 2012.). For this results we re-estimate θ for

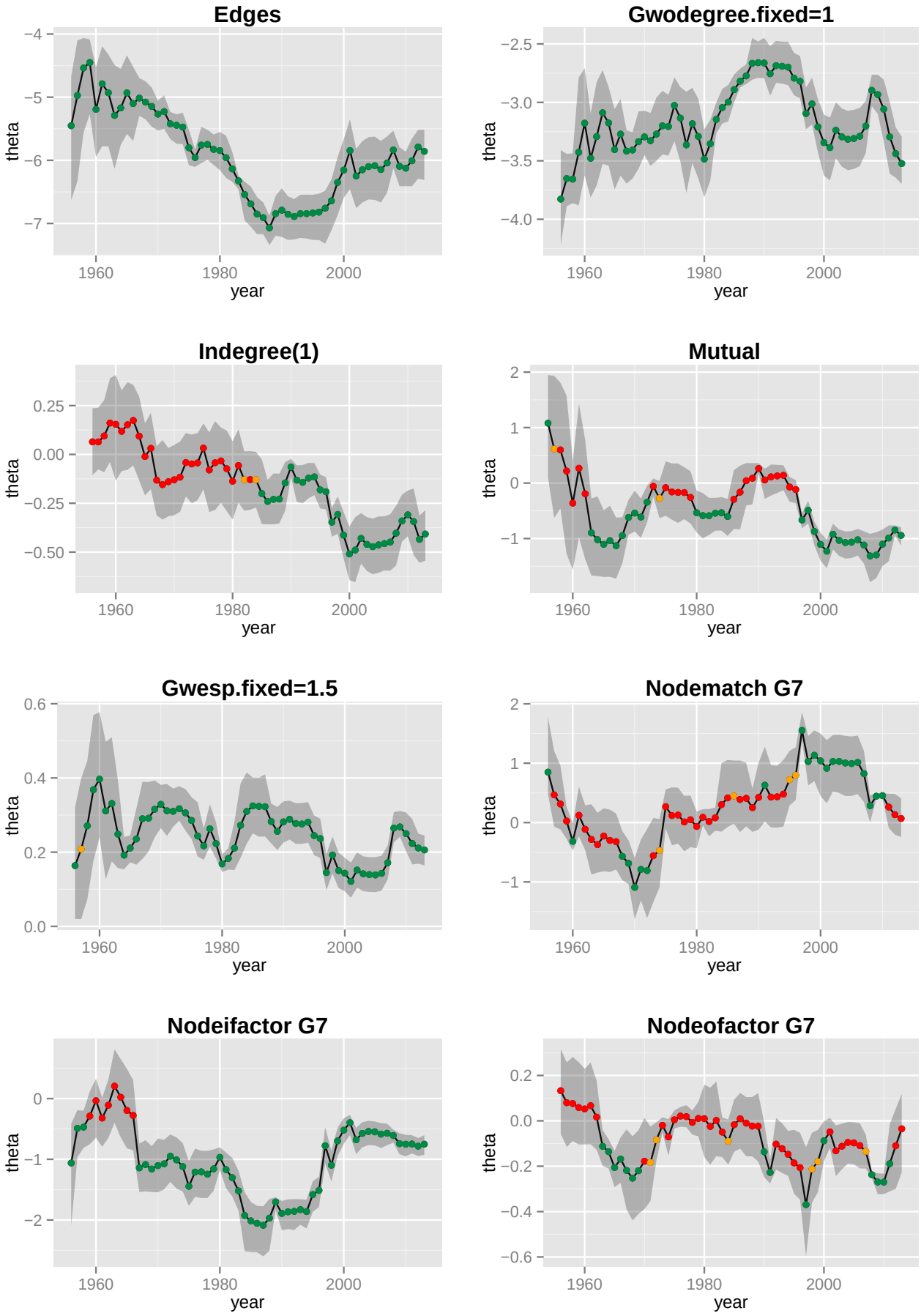


Figure 10: Time series of the estimated TERGM parameters for the time period 1956-2013

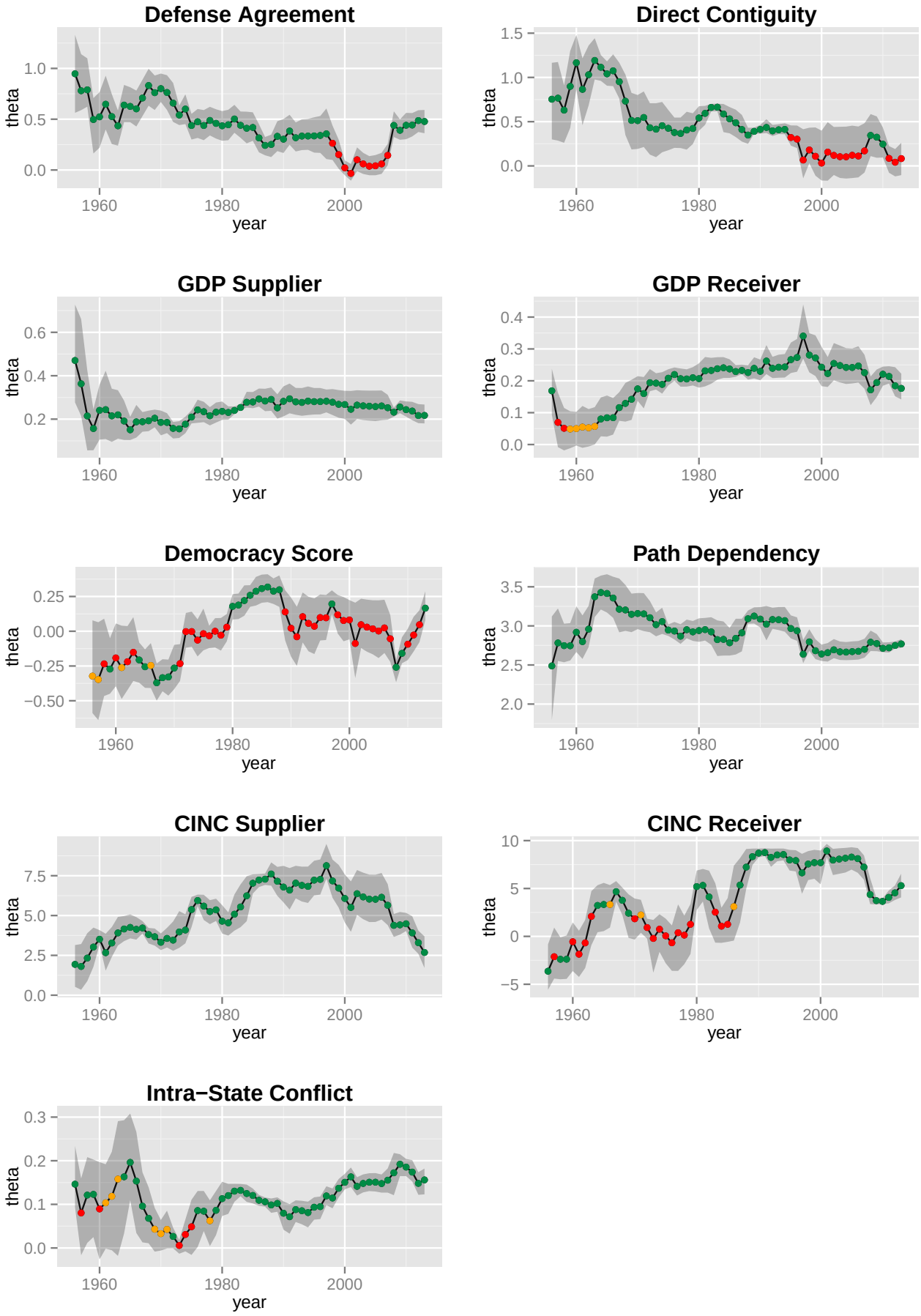


Figure 11: Time series of the estimated TERGM parameters for the time period 1956-2013

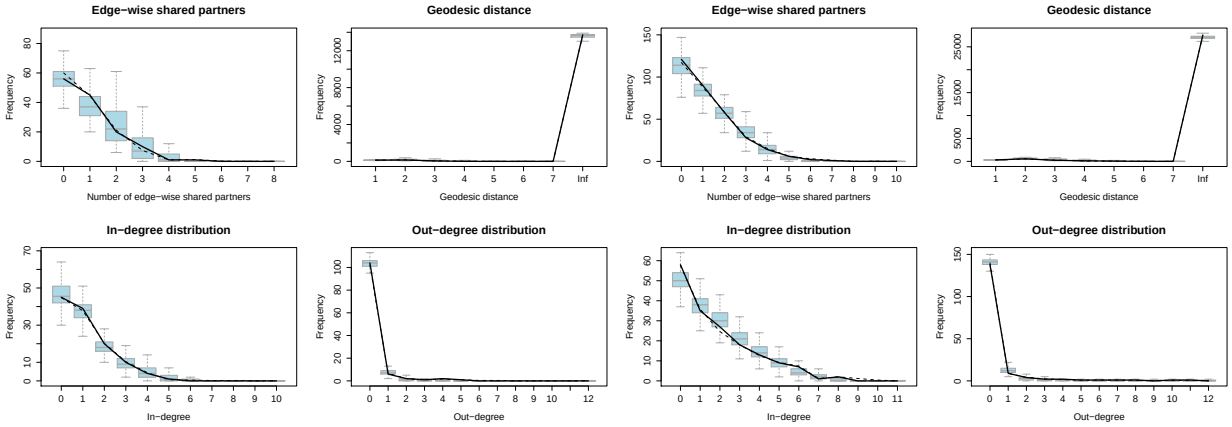


Figure 12: Goodness-of-fit diagnostics for the fitted TERGM of 1960 (four plots on the left) and of 1980 (four plots on the right)

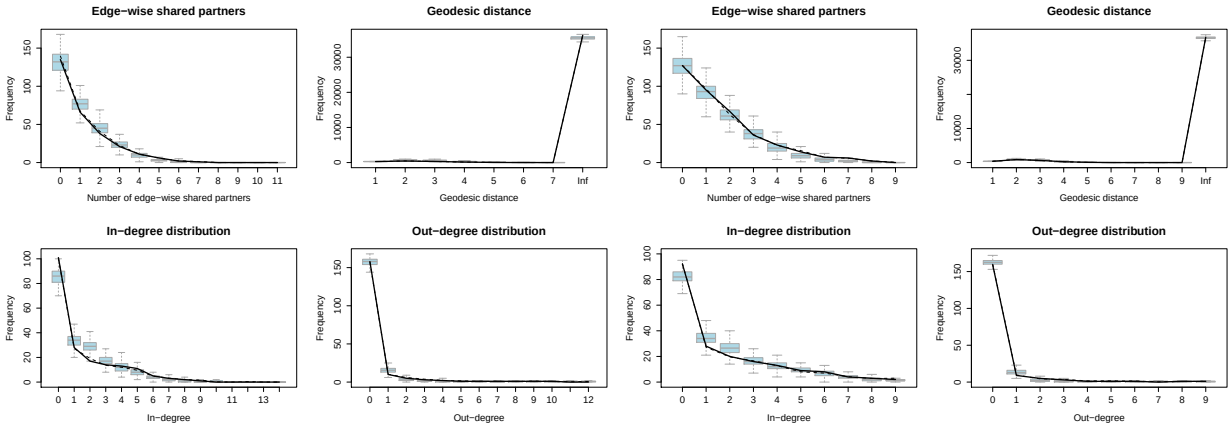


Figure 13: Goodness-of-fit diagnostics for the fitted TERGM of 2000 (four plots on the left) and of 2013 (four plots on the right)

each TERGM by excluding the latest of the five networks, and then simulating 500 new ones. As a next step we consider the area under the curve (AUC) of the receiver operating characteristc (ROC) in order to evaluate the model fit. Since the ROC visualizes the rate of the true positives against the rate of the false positives, i.e., the rate of correctly predicted dyads against the rate of the erroneously predicted dyads, the AUC provides the probability that a given observation is predicted correctly by the model. Consequently, the closer the AUC results are to 1, the better is the model. Therefore, the AUC time series qualify the model fit also as quite good.

As the arms trade network turns out to be a sparse network, we are also going to evaluate the fit of the network by the so-called precision-recall curve for statistical network models as proposed by Cranmer and Desmarais (2011). This approach has the crucial advantage over the out-of-sample AUC that it is not contingent on the number of realized edges. The precision, also known as the positive predictive value, describes the percentage of correctly predicted edges in the sample of predicted edges, while the recall, also known as sensitivity, is the percentage of correctly predicted edges in the set of actually existing edges. In figures 15 and 16 we plot the precision (y-axis) and the recall (x-axis) for each of the five years considered in one TERGM. The precision-recall curves show again that the predictive fit is good.

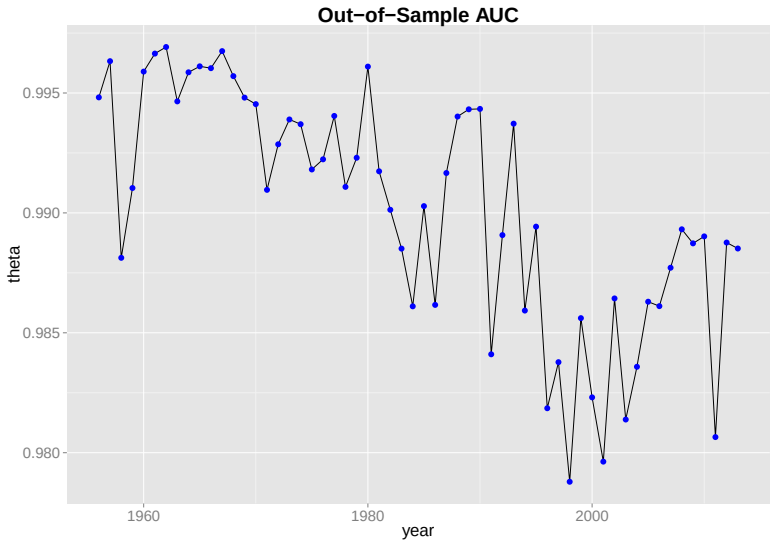


Figure 14: The results of the Out-of-Sample AUC simulation

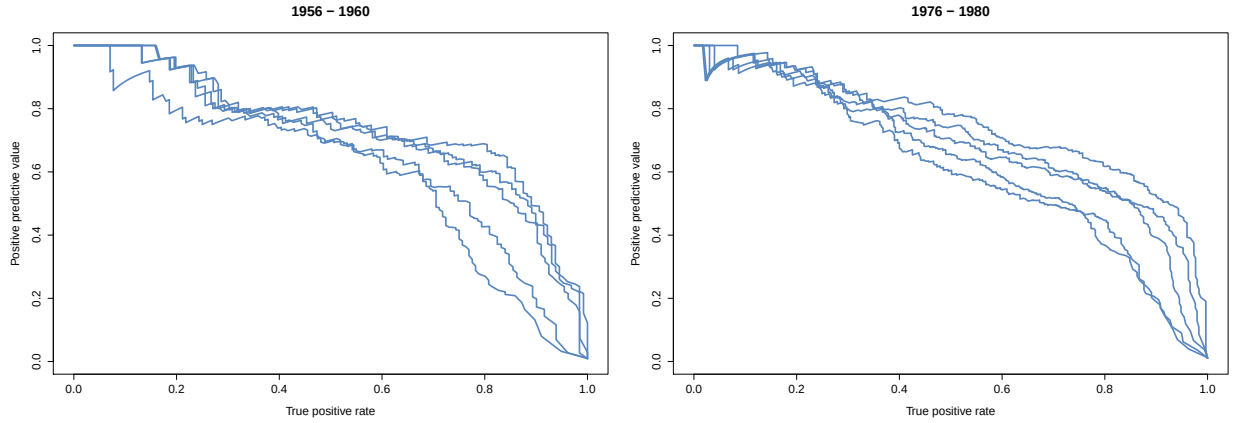


Figure 15: Precision recall curve of the TERGM of the time period 1956 – 1960 (right) and of the time period 1976 – 1980 (left)

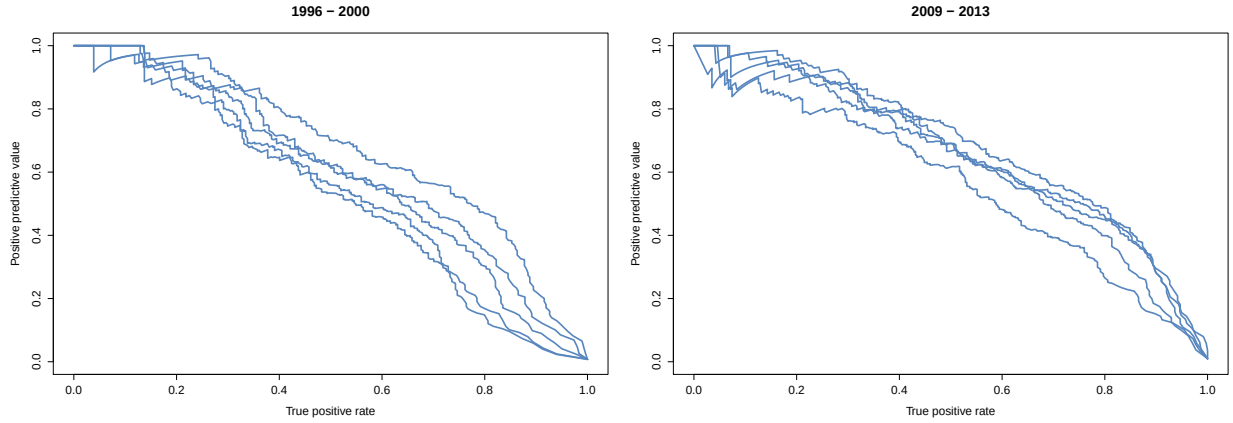


Figure 16: Precision recall curve of the TERGM of the time period 1996 – 2000 (right) and of the time period 2009 – 2013 (left)

Implications and Next Steps

Relying on network analysis, we systematically integrated supply and demand perspective for the international trade of arms. We offered a first network-analytic foundation for this very special type of market. The network perspective allows us to incorporate security as well as economic considerations into our models for all involved and non-involved countries. Our preliminary results partly corroborate previous results, but also give completely new insights into the time-specific impact of relevant country attributes and country relations. However, we consider those, still preliminary, findings on endogenous network processes as most important for the understanding of intrasectoral trade in strategic goods. These dynamics are so far unknown. Statistical network analysis is a prerequisite for the detection of these processes as for their forecasting. Admittedly We are still relyingon very simplified models. They will now be enriched by including explicitly those blocs having structured the Cold War in order to assess stability and change. Second, we will bring in temporality of network formation more explicitly. Finally, in order to become more realistic, the interdependence of choosing trade partners and the amount of trade has to be represented in ergm-based models.

Appendix

List of all Actors

In the following table, all countries and areas for which the MCW-data were collected by SIPRI are listed. The IDs correspond with the IDs used in the R-codes. The entry in the 'Years' column indicates the time period within which the corresponding country is included into the networks. A blank entry in this column denotes that this country existed during the whole time period of interest ($1950 - 2013$) and hence, is included in every network.

ID	Country	Years	ID	Country	Years
1	Abkhazia	since 1992	31	Burundi	since 1962
2	Afghanistan		32	Cambodia	since 1953
3	Albania		33	Cameroon	since 1960
4	Algeria	since 1962	34	Canada	
5	Andorra		35	Cape Verde	since 1975
6	Angola	since 1975	36	Central African Republic	since 1960
7	Antigua and Barbuda	since 1981	37	Chad	since 1960
8	Argentina		38	Chile	
9	Armenia	since 1991	39	China	
10	Aruba	since 1986	40	Colombia	
11	Australia		41	Comoros	since 1975
12	Austria		42	Congo, Democratic Repubic of	since 1960
13	Azerbaijan	since 1991	43	Congo, Republic of	since 1960
14	Bahamas, the	since 1973	44	Cook Islands	since 1965
15	Bahrain	since 1971	45	Costa Rica	
16	Bangladesh	since 1971	46	Cote d'Ivoire	since 1960
17	Barbados	since 1966	47	Croatia	since 1991
18	Belarus	since 1991	48	Cuba	
19	Belgium		49	Cyprus	since 1960
20	Belize	since 1981	50	Cyprus, Northern	since 1983
21	Benin	since 1961	51	Czech Republic	since 1993
22	Bhutan		52	Czechosloviakia	until 1992
23	Biafra	1967-1970	53	Darfur	since 2003
24	Bolivia		54	Denmark	
25	Bosnia and Herzegovina	since 1992	55	Djibouti	since 1977
26	Botswana	since 1966	56	Dominica	since 1978
27	Brazil		57	Dominican Republic	
28	Brunei Darussalam		58	Ecuador	
29	Bulgaria		59	Egypt	
30	Burkina Faso	since 1960	60	El Salvador	

ID	Country	Years	ID	Country	Years
61	Equatorial Guinea	since 1968	96	Kenya	since 1963
62	Eritrea	since 1993	97	Kiribati	since 1979
63	Estonia	since 1991	98	Korea, North	
64	Ethiopia		99	Korea, South	
65	Fiji	since 1970	100	Kosovo	since 2008
66	Finland		101	Kuwait	since 1961
67	France		102	Kyrgyzstan	since 1991
68	Gabon	since 1960	103	Laos	
69	Gambia	since 1965	104	Latvia	since 1991
70	Georgia	since 1991	105	Lebanon	
71	German Democratic Republic	1949-1990	106	Lesotho	since 1966
72	Germany		107	Liberia	
73	Ghana	since 1957	108	Libya	since 1951
74	Greece		109	Liechtenstein	
75	Grenada	since 1974	110	Lithuania	since 1990
76	Guatemala		111	Luxembourg	
77	Guinea	since 1958	112	Macedonia, FYROM	since 1991
78	Guinea-Bissau	since 1973	113	Madagasacar	since 1960
79	Guyana	since 1966	114	Malawi	since 1964
80	Haiti		115	Malaysia	since 1957
81	Honduras		116	Maldives	since 1965
82	Hungary		117	Mali	since 1960
83	Iceland		118	Malta	since 1964
84	India		119	Marshall Islands, the	since 1986
85	Indonesia		120	Mauritania	since 1960
86	Iran		121	Mauritius	since 1968
87	Iraq		122	Mexico	
88	Ireland		123	Micronesia	since 1986
89	Israel		124	Moldova	since 1991
90	Italy		125	Monaco	
91	Jamaica	since 1962	126	Mongolia	
92	Japan		127	Montenegro	since 2006
93	Jordan		128	Morocco	since 1956
94	Katanga		129	Mozambique	since 1975
95	Kazakhstan	since 1991	130	Myanmar	

ID	Country	Years	ID	Country	Years
131	Namibia		166	Sierra Leone	since 1961
132	Nauru	since 1968	167	Singapore	since 1965
133	Nepal		168	Slovakia	since 1993
134	Netherlands		169	Slovenia	since 1991
135	New Zealand		170	Solomon Islands	since 1978
136	Nicaragua		171	Somalia	since 1960
137	Niger	since 1960	172	Somaliland	since 1991
138	Nigeria	since 1960	173	South Africa	
139	Niue	since 1974	174	South Ossetia	since 1990
140	Norway		175	South Sudan	since 2005
141	Oman		176	Soviet Union	until 1991
142	Pakistan		177	Spain	
143	Palau	since 1994	178	Sri Lanka	
144	Palestine	since 1988	179	Sudan	since 1956
145	Panama		180	Suriname	since 1975
146	Papua New Guinea	seit 1975	181	Swaziland	since 1968
147	Paraguay		182	Sweden	
148	Peru		183	Switzerland	
149	Philippines, the		184	Syria	
150	Poland		185	Taiwan	
151	Portugal		186	Tajikistan	since 1991
152	Qatar		187	Tanzania	since 1961
153	Romania		188	Thailand	
154	Russia	since 1992	189	Timor-Leste	since 2002
155	Rwanda	since 1962	190	Togo	since 1960
156	Saint Kitts and Nevis	since 1983	191	Tonga	since 1970
157	Saint Lucia	since 1979	192	Trans-Dniester	since 1990
158	Saint Vincent and the Grenadines	since 1979	193	Trinidad and Tobago	since 1962
159	Samoa	since 1962	194	Tunisia	since 1956
160	San Marino		196	Turkey	
161	Sao Tome and Principe	since 1975	197	Turkmenistan	since 1991
162	Saudi Arabia		197	Tuvalu	since 1978
163	Senegal	since 1960	198	Uganda	since 1962
164	Serbia	since 1992	199	Ukraine	since 1991
165	Seychelles	since 1976	200	United Arab Emirates	since 1971

ID	Country	Years	ID	Country	Years
201	United Kingdom		210	Viet Nam, South	until 1976
202	United States		211	Western Sahara	since 1976
203	Uruguay		212	Yemen	since 1990
204	Uzbekistan	since 1991	213	Yemen, North	until 1990
205	Vanuatu	since 1980	214	Yemen, South	until 1990
206	Vatican (Holy See)		215	Yugoslavia, SFRo	until 1992
207	Venezuela		216	Zambia	since 1964
208	Viet Nam	since 1976	217	Zanzibar	since 1963
209	Viet Nam, North	until 1976	218	Zimbabwe	

List of Excluded Countries

We decided to exclude a handful of countries and areas from our networks, even though they are among the countries for which SIPRI gathered the data. A key reason is that these countries and areas are not recognized as independent, sovereign states by the majority of other states. Furthermore, the data sets used in this paper which were not created by SIPRI are usually missing data for these entities.

1	Abkhazia	6	Palestine
2	Aruba	7	Somaliland
3	Northern Cyprus	8	South Ossetia
4	Darfur	9	Trans Dniester
5	Niue	10	Zanzibar

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