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# Dyads Are Dead, Long Live Dyads! The Limits of Dyadic Designs in International Relations Research

Paul Poast
*University of Chicago*

Time and again, methodologists wrote papers with the potential to kill off dyadic designs in international relations research, only to pull back and—so long as one adopted the appropriate "tweak"—grant dyads a reprieve. Depending on the research question under consideration and the theoretical claims being evaluated, dyadic designs can provide valuable empirical insights. But these insights remain contingent on the researcher attempting to account for the limitations of dyadic data. To make this point, I concentrate on two difficulties for dyadic designs: the problem of interdependence and the problem of multilateral events. Drawing from empirical research on treaties and international organizations, I argue that a researcher need not abandon dyadic data so long as the researcher faces the former problem.

## Introduction

Dyads are dominant. After Bremer (1992)'s seminal work, state-to-state dyad years (such as USA-UK-1972) became the standard research design in quantitative international relations.[1] But the continued acceptance of dyads was not inevitable. Time and again, methodologists wrote papers with the potential to kill off dyadic designs, only to pull back and, so long as one adopted the appropriate "tweak," grant dyads a reprieve.[2]

Consider some examples. Temporal dependency between dyad-years produced inferential errors, but cubic splines offered dyads a second life (Beck, Katz, and Tucker 1998).[3] Quantal response equilibrium logit estimators overcame the inability of dyadic designs to capture strategic interdependence (Signorino 1999), while "neural networks" addressed the non-constant effect of covariates across dyads (Beck, King, and Zeng 2000). A 2001 *International Organization* symposium highlighted the problem of fixed unobserved differences between dyads, but, once again, the contributors spared properly adjusted dyadic designs from execution.[4] Subsequent work introduced a host of methods to account for various problematic features of dyadic designs: Bayesian bilinear mixed effects models (Hoff and Ward 2004; Hoff 2005; Ward, Siverson, and Cao 2007), spatial-lags (Neumayer and Plümper 2010), randomized testing (Erikson, Pinto, and Rader 2014), community detection (Lupu and Traag 2013), and nonparametric variance estimators (Aronow, Samii, and Assenova 2015). None of these papers advocated completely jettisoning dyadic designs.

What explains the methodologists' restraint? Why did those with the means to exterminate dyads offer ways of retaining them? Perhaps it is the dyad's intuitive appeal: it is convenient to use a research design that directly maps to the important theoretical notion of actor-to-actor interaction. Dyads, like any research design, constitute no more than an attempt to model reality; every model is wrong to a degree. If our findings are not *extremely* wrong when using dyadic designs (and we are not frequently interested in exact point estimates anyway), then so long as we acknowledge their shortcomings and diligently pursue the appropriate fixes, perhaps no harm comes from continuing to use dyads.

Cranmer and Desmarais (2016) offer a different message. They push scholars to altogether abandon the use of dyadic designs. Cranmer and Desmarais argue that dyadic designs only prove appropriate in the context of two assumptions: (i) that dyads do not influence or depend upon each other and (ii) no confounding between hyperdyadic dynamics and the dyadic covariates of interest. But according to Cranmer and Desmarais (2016, 11), these assumptions are "unreasonable" or, even worse, "untenable." Therefore, no conditions exist under which dyadic designs prove appropriate.

I fully agree with Cranmer and Desmarais that these assumptions are rarely (if ever) met when scholars conduct analysis on dyadic data *and* attempt none of the above mentioned methods to account for inferentially problematic features of the data—that is, by simply applying a standard logit estimator to pooled dyadic data. But does this make dyadic designs untenable? I answer in the negative. Depending on the research question under consideration and the theoretical claims being evaluated, dyadic designs can, contingent on the researcher accounting for the limitations in dyadic data, provide valuable empirical insights.

To make this point, I concentrate on two problems of dyadic designs: the problem of interdependence and the problem of multilateral events. I argue that a researcher need not abandon dyadic data so long as the researcher

Paul Poast is an assistant professor in the Department of Political Science at the University of Chicago.

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[1] Dorff and Ward (2013) credit Rudolph J. Rummel with introducing dyads to political science research during the 1960s.

[2] Many of the studies cited in the next paragraph offer replications of the Oneal and Russett (1997) study of the democratic peace.

[3] An alternative to the cubic splines solution is provided by Carter and Signorino (2010).

[4] The contributors disagree on the proper means of addressing the problem. Green, Kim, and Yoon (2001) advocate using a fixed-effects estimator. Beck and Katz (2001) argue that this is a bad idea (due to the loss of observations with no variation on the dependent variable). King (2001) advocates obtaining better data that captures the heterogeneity between observations.

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faces the former problem. I illustrate this point with reference to empirical research on international institutions, ranging from alliance pacts to trade and investment agreements.[5]

## The Problem of Interdependence

When we speak of interdependence, we refer to the direct or indirect influence of third parties on the actions of a dyad.[6] Such interdependence can be on the dependent variable, the independent variable, or both.[7] For an example of interdependence on the dependent variable, consider when we want to explain the signing of a trade agreement. The decision of states $i$ and $j$ to sign a trade agreement could likely influence whether states $j$ and $k$ sign a trade agreement. For an example of interdependence on the independent variable, consider when we use trade flows to explain an outcome. The flow from states $i$ to $j$ are likely influenced by the flow from $i$ to $k$.

Whether such interdependencies require abandoning a dyadic design depends entirely on the research question and the argument under evaluation. For example, geographic proximity constitutes one of the few variables that we consistently include and consistently code in our studies of alliance formation.[8] Whether one applies a logit/probit estimator on pooled dyads (Lai and Reiter 2000; Leeds et al. 2002; Gibler and Sarkees 2004; Gibler and Wolford 2006), uses a sociomatrix to include a variable capturing indirect relations (Maoz et al. 2007; Maoz 2010), estimates a Temporal Exponential Random Graph Model (tERGM) (Cranmer, Desmarais, and Kirkland 2012; Cranmer, Desmarais, and Menninga 2012), turns to a Stochastic Actor-Oriented Model (Warren 2010; Kinne 2013), or adopts a $k$-adic unit of analysis (Fordham and Poast, Forthcoming), geographic proximity between states is consistently found to be an important predictor of alliance formation. Hence, if one wants to study the influence of geographic distance on the decision of two states to form an alliance pact, then a dyadic design is likely just fine. But if one is interested in understanding change in the alliance network as a whole, then, as Cranmer and Desmarais (2016) point out, dyads will not do.

Neumayer and Plümper (2010) provide an excellent example of scholars accounting for interdependence in a dyadic study. They build from the work of Elkins, Guzman, and Simmons (2006) to analyze the formation of Bilateral Investment Treaties (BITs). By their very name, an analysis of BITs would seem tailor-made for dyadic data. Indeed, the dyad-year is the unit of analysis in both Neumayer and Plümper (2010) and Elkins, Guzman, and Simmons (2006). But BITs are subject to hyper-dyadic influences, such as how states $i$ and $j$ forming a BIT in year $t$ could affect whether $j$ and $k$ form a BIT in year $t+1$. Since dyads still offer an intuitive and conceptually simple means of evaluating BIT formation, Neumayer and Plümper (2010) do not abandon dyads. Instead, they include variables that directly model the spatial dependence between dyads (i.e., a BIT formed by the $ij$ dyad is influenced by the recent BIT formation decisions of dyads besides the $ij$ dyad, including the other dyads to which both $i$ and $j$ are parties). Neumayer and Plümper (2010) discuss very clearly the possible bias created by such interdependence, but their solution allows one to continue working within a dyadic framework.

Numerous other studies pose well-defined dyadic questions and test well-defined dyadic theories. To understand the creation of treaties managing labor flows between two countries, Peters (2011) adopts a dyadic design while controlling for the influence of third party states signing a treaty with the immigrant-recipient state. A dyadic design is sensible for Leeds and Savun (2007), since they wish to see how particular treaty provisions influence whether countries violate bilateral alliance treaties.[9] Since Wallace (2012) argues that the decision to violate the laws of war is largely dyadic—as compliance is influenced by whether the two parties are engaged in a war of attrition or one party is seeking to acquire the territory of the other—a dyadic design is reasonable.[10] A dyadic design makes sense for Johns and Pelc (2014), as they seek to understand how the characteristics of a complainant-respondent dyad induce third parties to join a formal World Trade Organization (WTO) trade dispute. Given their focus on rivers crossing the border between two states, Mitchell and Zawahri (2015) use dyads to determine if the design features of water cooperation treaties influence disputes over the water.[11] Carnegie (2014) adopts a dyadic research design to gauge the influence of joint WTO membership on trade flows between states with dissimilar capabilities, regime types, and foreign policies.[12] Because Wellhausen (2015) expects that foreign direct investment from nation $i$ to nation $j$ will decrease if a firm from nation $i$ sues host nation $j$ for breach of contract, a dyadic design is appropriate.

Again, research questions and theory should guide the decision of research design. Acknowledging the existence of hyper-dyadic influences is not, by itself, reason to completely abandon dyadic designs. Scholars must think carefully about possible third-party and systemic influences

[5] I am not considering here work that views borders as international institutions (Simmons 2005; Carter and Goemans 2011), though borders are a concept that naturally leads to dyadic analysis.

[6] Interdependence could be (i) how the relationship between A and B affects the relationship between A and C and between B and C or (ii) how the relative position of A within a larger network influences its relationship with B.

[7] I thank Brandon Kinne for pointing out this distinction.

[8] It is difficult to discuss variables that capture the actual international politics of alliances, such as the presence of common threats or regime similarity. The difficulty arises out of mixed results within the same study and/or between studies that use the same estimation approach. For example, depending on the model being estimated, Gibler and Wolford (2006), who use a probit estimator on pooled dyads, find the coefficient on common threat to be positive and statistically significant or positive and statistically insignificant (see also Powell 2010). With respect to a tERGM estimator, Cranmer et al. (2012) consistently find a positive and statistically significant coefficient on common threat, but Cranmer et al. (2011) find, depending on the variables included and the time period under consideration, the coefficient to be positive, negative, statistically significant, or statistically insignificant. A similar argument can be made for regime similarity. Gibler and Wolford (2006) find, depending on the model, that regime similarity either increases or has no influence on alliance formation. Cranmer et al. (2012) consistently find regime similarity to be a positive and statistically significant influence on alliance formation, but Cranmer et al. (2011) find it to be a consistently insignificant determinant of alliance formation. This likely points to a larger conceptual and theoretical problem within the alliance literature, not a problem with the estimation approach of these studies.

[9] A similar motivation guides the dyadic design in Mattes (2012b). Most importantly for the present paper, Mattes (2012a) uses a monadic approach and, in footnote 29, makes clear why a dyadic design is *not* appropriate.

[10] Morrow (2007) also argues that compliance is determined at the dyad level since both parties must have ratified the POW treaty.

[11] See also Zawahri and Gerlak 2009; Zawahri and Mitchell 2011.

[12] Davis (2004) captures the influence of different GATT rounds, not only the WTO, on agreements to liberalize trade within the US-EU dyad and the US-Japan dyad.

and then seek to account for such influences. But the presence of these influences need not automatically result in abandoning dyads.[13]

### The Problem of Multilateral Events

More troublesome for dyadic designs are multilateral events. To keep the discussion concrete, think of a multilateral event as when three or more parties sign a treaty.[14] When using dyadic data and faced with a multilateral event, it is common to divide the single multilateral event into its constituent dyads.[15] For example, if states *i*, *j*, and *k* form a treaty in year *t*, then this procedure identifies dyads *ij*, *ik*, and *jk* as each forming a treaty in year *t*.[16] Though scholars frequently point to the problems of dividing a multilateral event's participants into their constituent dyadic combinations (Croco and Teo 2005; Gibler and Wolford 2006, 141; Cranmer, Desmarais, and Menninga 2012, 283–6), Poast (2010) confirmed the substantial bias this produces in regression estimates. The source of the bias is measurement error in the independent variables. For example, suppose that in the true data generating process, the size of the largest country (in terms of population) in a group (in which the group contains more than two states) influences multilateral alliance formation. With dyadic data, the researcher can only compare the size of two countries. But this latter ratio (with two states in the denominator) is not the same as the former ratio (with three or more states in the denominator).

It is highly unlikely that multilateral events can be made to fit within a dyadic research design.[17] This is because an event being multilateral is distinct from interdependence between dyads. When dyads are interdependent, the probability that the *ij* dyad forms a treaty is influenced by not only the characteristics of the *ij* dyad but also the characteristics of the *jk* dyad and the *ik* dyad. In contrast, a multilateral process is akin to a systemic process on a smaller scale, in that the whole is fundamentally different than the sum of the parts.[18] Stated differently, all three dyads(*ij, ik*, and *jk)* influence one another but lead to an outcome—a trilateral treaty—not captured by any of the dyads.

To analyze a multilateral event, I see two potential approaches. Neither approach relies on dyadic research designs. These approaches are network analysis and *k*-adic research designs.

The first approach uses the tools of network analysis. For example, Hollway and Koskinen (2015a, 2015b) use a multilevel ERGM to explain why states enter bilateral or multilateral fisheries agreements. This approach points to country-specific factors that drive states to pursue either multilateral treaties or bilateral treaties.[19] This approach also reveals how multilateral ties and bilateral ties lead to different network clusters (for example, cooperation in multilateral agreements could lead to a series of bilateral agreements or cooperation in several bilateral agreements could enable the creation of a multilateral agreement) and accounts for how multilateral and bilateral treaties interlock with one another. Multilevel ERGMs may also identify when a group's characteristics lead to a multilateral agreement (for example, the relative power or the number of major powers in a group increases or decreases the probability of treaty formation). In other words, this method can account for when a group of states decides, *as a group*, to create a multilateral agreement.

But there is no automatic link between the tools of network analysis and the ability to analyze multilateral events. Though network analysis can explain why a set of nodes are connected, they can fail to qualitatively identify the multiple connections' source. Consider the concept of "triadic closure." This means an edge connects nodes *i* and *j*, an edge connects nodes *i* and *k*, and an edge connects nodes *j* and *k*.[20] In the context of alliance treaties, triadic closure shows, for example, the influence of a particular third party on treaty formation between two other states (e.g. countries *i* and *j* are allied because of countries *i* and *k* being allied *and* countries *j* and *k* being allied). But the problem of multilateral events forces scholars to ask an important question: is this instance of triadic closure the product of three separate bilateral pacts or one trilateral agreement? We do not simply want to know the existence of triadic closure or even the cause of triadic closure; we want to identify the means of accomplishing triadic closure (for example, a series of bilateral pacts or a single multilateral pact).[21]

[13]This same argument applies to monadic research designs. When analyzing the effects of regime type on trade policy, Chaudoin, Milner, and Pang (2015) account for system level factors in a multilevel model. Interested in the effect of human rights organizations within a country, Bell, Clay, and Murdie (2012) account for the spatial influence of such organizations in neighboring countries.

[14]According to Koremenos (2013, note 4), multilateral treaties are quite common, with over 4,000 registered original multilateral treaties in the United Nations Treaty Series (as of the date of publication of her article).

[15]A less commonly applied alternative is to choose, at random, one of the dyadic combinations from the multilateral event (see Bennett and Stam 1996). With respect to dividing the multilateral event into its constituent dyads, Vasquez and Valerino (2010) acknowledge how this procedure can artificially inflate the number of "events" in a dyadic framework, but they conjecture that, in the context of multilateral wars, this procedure may still accurately reflect the actual decision making of participants: they hold that participants in multilateral wars only consider one opponent at a time.

[16]Zawahri and Mitchell (2011) adopt a slightly different approach when analyzing the decision of states to join river management agreements. They run two separate analyses: in one analysis they identify in year *t* if a dyad became members of a bilateral treaty and in another analysis identify if in year *t* a dyad became members of a multilateral treaty.

[17]I am focusing on the multilateral event being the dependent variable. However, as with interdependence, a multilateral event could apply to the independent variable. For example, Powers (2004) explores whether joint membership among African states in regional trade agreements with alliance provisions (such as ECOWAS) influences the probability of conflict onset between two states. Since ECOWAS is a multilateral institution, the notion of "joint membership" is derived from a multilateral event. Given that this characterizes numerous studies that use "Joint International Organization Membership" as an independent variable (Oneal and Russett 2001; Shannon 2009), the consequences of a dyadic variable being the product of a multilateral event must be explored (as a useful initial step applying network analysis tools to the question of joint IO membership's effect, see Dorussen and Ward 2008).

[18]It is also distinct from dyadic diffusion. When the process is one of dyadic diffusion, the probability of the *ij* dyad forming a treaty is influenced by the probability of the *jk* dyad forming a treaty and the probability of the *ik* dyad forming a treaty.

[19]For example, they find that fishing intensity leads to the pursuit of bilateral agreement while the desire for conservation leads to multilateral agreements.

[20]Also referred to as a "transitive triple."

[21]A similar critique applies to the concepts of *k*-stars and *k*-triangles (Pattison, Robins, and Handcock 2006; Snijders et al. 2007; Hunter and Handcock 2006). A *k*-star indicates that a single node is connected to *k* other nodes. Though useful for conceptualizing the extent that individual nodes are connected to multiple nodes, the *k*-star statistic does not indicate if the connections are due to a single multilateral event or separate bilateral events. A *k*-triangle statistic indicates the number of triadic relationships that share an edge (for example, the number of third parties to which *i* and *j* together are tied). But it does not make clear whether this occurs because *i* and *j* formed a series of trilateral agreements or each formed bilateral agreements with one another and the same third party state.

The second approach uses *k*-adic data (Poast 2010). A *k*-ad is a unit of analysis comprised of $k \geq 2$ members. This means dyads are *k*-ads where *k* is limited to 2. A *k*-adic dataset would contain, in addition to dyads, triads ($k=3$), quad-ads ($k=4$), penta-ads ($k=5$), all the way to $k=n$, where *n* is the largest grouping of states desired by the analyst. *K*-ads code, within the dataset itself, whether actors are connected in a single multilateral event or are connected via a series of bilateral events. For example, suppose states *i*, *j*, and *h* formed a multilateral treaty in year *t*. In this case, the triadic observation containing states *i*, *j*, and *h* in year *t* is coded as having formed a treaty, but the three dyads of *ij*, *ih*, and *jh* are coded in year *t* as having not formed treaties. In contrast, suppose states *i*, *j*, and *h* formed three separate bilateral treaties in year *t*. In this case, the three dyads of *ij*, *ih*, and *jh* are each coded as having formed treaties in year *t*, but the *i*, *j*, and *h* triad is coded as having not formed a treaty in year *t*. In other words, a *k*-adic design—by including all of the dyadic combinations of *i*, *j*, and *h*, along with the triad *i-j-h*—explicitly distinguishes multiple bilateral connections from a single multilateral connection.

*K*-adic data have drawbacks. One is the enormous number of observations. Scholars commonly use all possible dyads in dyadic research designs.[22] But using all combinations of states in a *k*-adic research design (from $k=2$ to $k=n$, where $n>2$) could create an enormous, perhaps computationally infeasible, number of observations. For example, with 100 countries in a dataset, all combinations of 100, 99, 98, 97, . . . , down to 2 countries will result in a dataset of $1.26765 \times 10^{30}$ observations! To address this concern, Poast (2010, 410) recommends applying choice-based sampling techniques. Another option is a "politically relevant" *k*-ad approach, whereby the analyst only considers *k*-ads that meet set criteria (for example, only *k*-ads comprised of states in the same region or only *k*-ads that have at least one major power). Either approach could generate reasonably sized datasets.[23]

A second drawback to *k*-adic data is the need to account for the interdependencies between *k*-ads. Given the aforementioned large number of *k*-adic observations, this is not a trivial problem. However, just as one can account for interdependencies in dyadic research designs, one can account for interdependencies in *k*-adic data.[24]

Neither network analysis nor *k*-ads offer a perfect solution to the problem of multilateral events. However, both approaches, relative to dyadic designs, better capture multilateral phenomenon. Indeed, *k*-adic data and the tools of network analysis could work together to provide a deeper understanding of world events.[25] Consider the years preceding World War I. During this time, Germany, Italy, and Austria-Hungary formed the Triple Alliance. In response, France and Russia formed a bilateral alliance. The grouping together of these opposition coalitions led the British periodical *Saturday Review* to remark on August 8, 1891, that:

> The balance of power—which parrot-pedants laugh at as a thing out of date, and which is about as much out of date as the multiplication table – is capable of being better preserved by two combinations than by one, if the Power which holds the middle of the see-saw knows how to use its position. And by history and geography, by interest and temperament, Great Britain is the Power which ought to hold that middle.[26]

Hence, network analysis tools could be employed to understand the interactions between the Germany-Italy-Austria *k*-ad, Russian-French *k*-ad, and the British node during the late nineteenth and early twentieth centuries.

## Use Dyads, but Proceed With Caution

Where does this leave researchers? The complex interactions between states in the international system create two problems for scholars wishing to conduct quantitative analysis of international events: the problem of interdependence and the problem of multilateral events. The former problem need not result in throwing out dyadic designs. If the research question pertains to a bilateral event and the posited theory concerns bilateral characteristics, then a "tweaked" dyadic approach could work. Whether the "tweak" addresses time dependencies, spatial interdependence, unit level heterogeneity, or some alternative problem is study-specific. But if scholars are careful to think through and account for the theoretically important sources of bias generated by interdependence, dyadic designs can still prove fruitful.

The latter problem, however, proves more problematic for dyadic research designs. If one studies a multilateral event, then dyads are out. Additionally, if one studies a system as a whole, or poses a system-level explanatory variable, then dyads are likely inappropriate. Though I disagree with Cranmer and Desmarais (2016) that scholars should abandon dyadic research designs, they do provide a useful note of caution: our empirical efforts can go awry if we blindly use dyadic data without thinking through the possible interdependencies and third-party influences that could undermine our inferences.

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[22]These are in either an undirected format (for example, only dyad *ij* appears in the dataset) or directed format (for example, dyads *ij* and *ji* appear in the dataset).

[23]New software from Bennett, Poast, and Stam (2015), called *NewGene*, offers a means of constructing such *k*-adic datasets (www.newgenesoftware.org).

[24]Depending on the theory being tested, the tools of network analysis may very well offer a way of accounting for the interdependencies between *k*-ads.

[25]One direction for combining the two is to leverage bipartite/two-mode networks. A bipartite network consists of two node sets—a group of "actors" and a group of "events"—in which actors have ties to events. One can then model the tie probabilities between the two sets. Because this approach is agnostic about dyads, triads, quad-ads, etc., it could be useful in issue areas in which a wide variety of *k*-adic outcomes are possible.

[26]Quoted in Langer (1929, 200).

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