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John A. C. Conybeare
University of Iowa

Todd Sandler

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THE TRIPLE ENTENTE AND THE TRIPLE ALLIANCE 1880–1914: A COLLECTIVE GOODS APPROACH

JOHN A. C. CONYBEARE
University of Iowa
TODD SANDLER
Iowa State University

The distribution of burdens in alliances may be explained in terms of public and private outputs. A joint product model is applied to the Triple Alliance and Triple Entente, using generalized least squares–auto regressive moving average (GLS–ARMA) techniques and time series data. Results indicate that countries regarded allies' military effort more as complements than as substitutes, though several examples of free-riding behavior are noted. The method used here may provide more accurate estimation of publicness problems than is found in the usual static tests.

Olson and Zeckhauser (1966) modeled the North Atlantic Treaty Organization in the 1960s as sharing the pure public good of strategic nuclear deterrence. Deterrence is a pure public good when its benefits are nonrival and nonexcludable. However, alliances also rely on conventional weapons subject to both partial rivalry and excludability. Consequently, conventional weapons yield benefits of an impure public nature,[1] and may be analyzed with a joint product model in which defense activities are viewed as providing multiple outputs, public *and* private. Empirical tests of the joint product model have been made by Murdoch and Sandler (1984, 1986).

Thies (1987) examined a host of pre-World War II alliances that depended on conventional armaments producing deterrence as well as impure public benefits such as damage-limiting protection in times of conflict. Based on a visual examination of some income and military spending data, Thies (1987) concluded that most of these alliances demonstrated behavior more in keeping with the joint product model for which allies are motivated by private excludable defense benefits. Our purpose is to examine the Triple Alliance and the Triple Entente for the period 1880–1914. We present a joint product model and two-stage generalized least squares estimates of each ally's demand for defense over time.

History and Analyses of Pre-1914 Alliances

The oldest of the alliances was the Dual Alliance between Germany and Austria-Hungary, signed in October 1879, and joined by Italy in May 1882, transforming it into the Triple Alliance.[2] The former remained in force until 1918; the latter ended with Italy's declaration of war on the central powers in 1915. The Dual Alliance pledged assistance if one party was attacked by Russia and at least neutrality if attacked by another power. The Triple

Alliance was directed primarily against France. It required aid by the other two members if one of them were attacked by France or became involved in a war with two or more other great powers and neutrality if one member initiated war with a nonmember. Italy's membership in the Triple Alliance was never considered firm enough to be reliable in the event of war. Italy and Austria had major territorial disputes. Italy and France settled their differences and signed agreements (December 1900 and November 1902) obliging Italy to remain neutral in the event of France becoming involved in a war with a third party. An Italo-Russian entente in October 1909, with mutual pledges of support in their respective spheres of influence (North Africa and the Balkans), drove another wedge between Italy and its nominal allies in the Triple Alliance.

Russia was associated with the Triple Alliance until 1890. The Alliance of the Three Emperors (June 1881) pledged neutrality in the event of any signatories becoming involved in a war with a fourth party. It was replaced in June 1887 with the Russo-German Reinsurance Treaty, again pledging neutrality in the event of war with a third party, but with two exceptions: German initiation of war against France and Russian initiation of war against Austria. The treaty was allowed to lapse in 1890, following Bismarck's dismissal and despite Russia's desire for renewal.

The Triple Entente was composed of three bilateral accords. The first was a military convention between France and Russia (December 1893), following closely on Germany's refusal to renew the Reinsurance Treaty. Each pledged support for the other in the event of attack by a Triple Alliance power as long as Germany was involved either directly or in a supportive role. The Anglo-French Entente of April 1904 settled some of their considerable colonial differences. The Anglo-Russian Entente completed the prewar pattern of major power alliances, although it nominally did nothing more than defuse mutual tensions in Asia. Neither entente was originally directed against Germany.

The Triple Entente did not (with exception of its Franco-Russian component) entail any specific guarantees of military support, and its component elements were originally mere settlements of extra-European issues. However, once the ententes were signed, "military conversations" followed. In the case of France and Britain, military planning (initiated in 1906 and continued until the outbreak of war) took the form of an agreed division of labor in the event of war with Germany: Britain would concentrate on the war at sea and France on the land war. Anglo-Russian military planning did not begin until June 1914.

There is a voluminous literature on international politics before World War I. Most diplomatic histories, aside from personal memoirs, have focused on the structure of the system and in particular on the reasons why war broke out in 1914 (e.g., Hinsley 1967 and Schroeder 1976). The most-cited factor is the alleged decline in the fluidity of the alliance system and the changing objectives of the great powers. The quantitative literature on nineteenth-century alliances has been mostly devoted to testing propositions derived from the balance-of-power model. Quantitative studies confirm, for example, that the pattern of nineteenth-century alliances was random (Li and Thompson 1978). Despite the intellectual attention devoted to the pre–World War I system, there have been no attempts, aside from Thies (1987), to explicate problems of intra-alliance distribution of defense effort.

Theoretical Model

The joint product model views the arsenal of each ally as providing multiple outputs that may be private (i.e., country-specific, such as protection of colonies), purely public (i.e., nonrival and nonexcludable, such as deterrence against attack), or impurely public between allies (i.e., partially rival and/or partially nonexcludable, such as defense in times of active attack). This public-private distinction concerns nonrivalry and nonexcludability of benefits *between* allies but not necessarily within each ally.

In the case of pre-World War I alliances like the Triple Alliance and the Triple Entente, conventional armaments, in the form of land and navy forces, comprised the arsenals. Such forces are subject to spatial rivalry in the form of thinning (i.e., fewer forces per mile of perimeter, or fewer forces per square mile of area), as more allies rely on a fixed arsenal and its troops. In this case, defense benefits display partial rivalry and cannot be considered to be purely public. Deployment decisions imply excludability for allies furthest from the troops and matériel. Since even conventional forces may deter a potential aggressor from attacking allied nations, some pure public benefits were nevertheless present in these early alliances.

Although the joint product model encompasses the pure public good model, the former may lead to vastly different burden-sharing behavior. Olson and Zeckhauser (1966) demonstrated that the presence of pure public defense benefits implies that (1) the large, rich allies will shoulder the military burdens of the smaller allies; (2) the allocation of resources will be suboptimal with respect to the defense activity; and (3) free riding will occur as an ally reduces its defense commitment in response to an increase in that of the other allies.

The presence of joint products means that the consumption relationship of the jointly derived defense goods plays a role when analyzing free rider behavior. If, for example, the joint products are complementary in consumption (i.e., they enhance one another's marginal valuation), an increase in the other ally's defense output in the form of greater deterrence may augment an ally's own desire to provide defense owing to its need for the private component associated with its own military activity. An ally may therefore respond positively to an increase in the other allies' military activities. Moreover, defense benefits among allies will be shared according to the ratio of private and excludable benefit to total benefits derived from the military activity. Allies that receive relatively more private benefits will spend more on defense; hence, defense burdens among allies will be based in part on private benefit shares rather than economic size.

For alliances relying on conventional armaments, defense benefits are more likely to be complementary since troops and artillery deployed along one border cannot defend a spatially separated border elsewhere in the alliance. In fact, increased fortification of one ally's boundary may induce other allies to follow suit so as not to invite an enemy to direct the assault at the now-relatively-less-fortified perimeter. A negative externality is now at play when allies fortify their borders and territories—that is, the likelihood of an attack elsewhere in the alliance increases. Since the increased military activity of any ally also deters aggression from an adversary, a positive externality is also present.

We now sketch the formal theoretical model. Consider an n-country alliance dependent on conventional armaments. For a representative ally, let x stand for the private defense output, z for the public defense output, and q for the conventional military activity. The ally is indexed with an i, which is suppressed where possible to simplify notation. The joint product relationships in the ith ally are

$$x = f(q) \tag{1}$$

and

$$z = g(q), \tag{2}$$

where $dx/dq = f' > 0$ and $dz/dq = g' > 0$ and both $f(q)$ and $g(q)$ are strictly concave, twice-continuously-differentiable functions. The first derivative of f and g measures the respective marginal productivities of the military activity in providing a private output and alliancewide defense. The quantity of alliancewide defense provided by the *other* allies, denoted by $\tilde{Z}$, affects an ally's decision to build up its own defense. We will refer to the protection benefit derived from an ally's provision (of arsenal and/or troops) as a "spillin." It can be proxied by a physical flow variable (e.g., manpower per period). In total, the allies consume Z units of public protection, where

$$Z = z + \tilde{Z}. \tag{3}$$

If the origin of spillin is important, spillins can be written as

$$\tilde{Z} = \sum_{j \neq i}^{n} g_j(q_j), \tag{4}$$

where $g_j(\bullet)$ relates the defense activity in ally j to the number of units of alliancewide protection added by this ally's activity, namely, z_j. In equation 4, $g_j' > 0$ and $g_j'' < 0$, for all j.

The preferences of a representative, though not necessarily identical, ally are depicted by a well-behaved, strictly concave, nonsatiable utility function,

$$U = U(y, x, Z, T), \tag{5}$$

where y is a private *numéraire* activity and T is a threat variable that could correspond to the sum of the military activity in the opposing alliance.[3] If, however, the opposing nations are viewed differently by a potential adversary, threat would be the *vector* of military manpower of the allies in the threatening alliance. In either case, $\partial U/\partial T = U_T < 0$. An increase in threat lowers utility. Substituting equations 1–4 into equation 5 allows us to express the utility function in terms of activity space:

$$U = U[y, f(q), g(q) + \sum_{j \neq i} g_j(q_j), T]$$
$$= U(y, q; q_{-i}, T), \tag{6}$$

where $q_{-i} = (q_1, \ldots, q_{i-1}, q_{i+1}, \ldots, q_n)$. To derive an ally's demand equation for military activities, a resource or budget constraint,

$$I = y + pq, \tag{7}$$

must limit utility maximization, where I is national income, p is the relative costliness of the military activity, and the price of good y is normalized at a value of one.

Maximizing utility in equation 6 subject to equation 7 and to the constancy of q_{-i} and T yields a set of first-order conditions (FOCs) that can be used to derive an ally's demand for its own military activity. The vector q_{-i} is held constant at the best-response level of the rest of the allies, since a Nash equilibrium underlies our representation of the game structure for the allies' interactions. A Nash equilibrium is achieved when each ally desires an allocation (y^e, q^e) that satisfies its own first-order conditions. Furthermore, at equilibrium *all* allies must be simultaneously satisfying their FOCs. In essence, the best-response level for q_{-i} is the equilibrium vector q^e_{-i} in which each component fulfills the respective ally's FOCs. At equilibrium, the FOCs implicitly define an ally's demand for military activity in terms of the exogenous variables;[4] hence, this demand is

$$q = q(I, p, q_{-i}, T). \tag{8}$$

In the empirical section, equation 8 is estimated for allies in the two pre–World War I alliances. Since we do not have price data on the relative costliness of defense output as compared to private nondefense outputs, we are forced to drop p as an argument. This causes no bias, provided that *relative* prices remain constant over time. In equation 8, the comparative static derivatives $\partial q/\partial I$, $\partial q/\partial q_j$, and $\partial q/\partial T$ prove of interest. Based upon Murdoch and Sandler (1984), these derivatives can be signed a priori in some special cases. The derivative $\partial q/\partial I$ measures the effect of a national income change on an ally's demand for military activity. When defense is a normal good with positive income elasticity, this derivative will exceed zero.

The derivative $\partial q/\partial q_j$ indicates an ally's defense response to an increase in the jth ally's defense activity. Since each ally can receive potential spillins from $n - 1$ allies, there are $n - 1$ responses —that is, $\partial q/\partial q_j$ for $j \neq i$. The sign of these responses are positive when spillins are viewed as complementary to an ally's own defense efforts. If, however, these qs are viewed as substitutes, as in the case of pure public goods, this derivative is more apt to be negative or near zero. Finally, the derivative $\partial q/\partial T$ depicts an ally's defense response to threat. When threat is perceived as significant and increasing, a positive defense response is expected.

The model disaggregates spillins by place of origin (e.g., Austria might respond differently to Germany than to Italy), but can be modified to allow spillins to be perfectly substitutable regardless of place of origin. Replace equation 4 with $\tilde{Z} = h(\tilde{Q})$, where

$$\tilde{Q} = \sum_{j \neq i} q_j$$

and denotes the other allies' aggregate defense activity. Equations 1–3, 5, and 7 remain unchanged. The utility function becomes $U = U(y, q; \tilde{Q}, T)$, and the estimating equation

$$q = q(I, p, \tilde{Q}, T). \tag{9}$$

The rest of the allies' military activity, $\tilde{Q}$, replaces the vector q_{-i} in equation 8. If threat is also disaggregated by country, T would be a vector of manpower levels rather than the sum of military manpower in the opposing alliance.

Statistical Model

The variables are listed in the Appendix. National income (*INC, where * is a single-letter country designator) data were obtained from Crafts 1983 and Mitchell 1975. Military manpower (*MIL) is reported by the *Statesman's Yearbook* (1879–1914). Threat variables are lagged one period (L*MIL), since a threat must be realized before it is observed; and spillin variables are estimated (*MILE) as the first stage of the two-stage GLS procedure that will be described. Combinations of two or more countries are added to the variable label (e.g., LFRUMIL is the lagged combination of British, Russian, and French military manpower). Changes in alliance composition are detected by changes in *slope* coefficients. A dummy variable (DXY = 1, when alliance between X and Y is in operation) records alliance entry or exit and is multiplied by the estimated military manpower of the country entering or leaving the alliance. Hence, DGR • RE, for example, is a dummy for the Russo-German alliance multiplied by estimated Russian manpower. The coding of the dummy is lagged so that changes in the value of the variable only take effect after one full year of any change in alliance composition.

Estimation of equations 8 and 9 take the form *MIL = f(INC, SPILL, THREAT, SHIFT), where *MIL denotes q, INC depicts GNP or I, SPILL indicates either the allies' aggregate spillins ($\tilde{Q}$) or a vector of allies' spillins (q_{-i}), THREAT reflects the opposing alliance's military proxy, and

SHIFT measures changes in alliance composition. Our estimating equation is

$$*\text{MIL}_t = \beta_{0t} + \beta_{1t}*\text{INC}_t + \beta_{2t}\widehat{\text{SPILL}}_t + \beta_{3t}\text{THREAT}_{t-1} + \beta_{4t}(\text{D} \bullet \widehat{\text{SPILL}}_t) + \epsilon_t. \quad (10)$$

The simultaneity of the country equations was dealt with by utilizing a two-stage least squares process. The SPILL variables were estimated first (this corresponds to the "hats" over SPILL in equation 10), using as regressors the incomes of all alliance partners, the ally's own income, binary (intercept shift) dummies for any alliance in which the country entered or exited during the period (D**), and the exogenous threat of the opposing alliance (LGAIMIL or LFRUMIL). The linear estimates of SPILL were then used for the final estimation of equation 10, using GLS-ARMA (with first-order autocorrelation of residuals), since ordinary least squares estimations resulted in positive autocorrelation.

Results

Results for the Triple Entente and Triple Alliance are presented in Tables 1 and 2, respectively. Since collinearity reduces significance levels, we place some emphasis on coefficients whose values are nearly significant. The positive income coefficient (significant in all cases except Italy) suggests that defense is a normal good. Aggregating the threat and SPILL variables proved unfruitful in some cases, because countries responded to different allies or opponents in different ways. Given the lack of rigidity in the prewar alliance system and the variety of different forms of understandings, this is not surprising. Threat has the expected sign in the majority of cases but is only significant for France. Where the threat sign is negative, it is not statistically significant and is in two cases (Russia reacting to the Triple Alliance and Germany reacting to Russia) limited to situations in which the countries in question had been on friendly terms even though they would eventually be in opposing alliances. Taking the period 1880–1914 as a whole, the positive spillin coefficients suggest little evidence of free riding between countries allied during some part of the period. France and Russia (free riding on one another) are the only exceptions. The slope shift coefficients, however, are predominantly negative (with the exception of France) and typically insignificant, indicating weak evidence of free-riding reactions to alliance formation.

Britain's positive reaction (Table 1) to both major allied groups throughout the period is consistent with the long-standing objective of "splendid isolation," regarding all other major powers as potential enemies. The positive coefficient on spillins (i.e., FRMILE) is nearly significant and suggests complementarity of forces. A larger positive (but insignificant) coefficient is associated with the Triple Alliance. The negative and significant coefficient associated with the alliance slope shift for the Anglo-Russian Entente suggests some substitution of forces once the United Kingdom abandoned splendid isolation. The entente with Russia helped Britain by both relieving military pressure on Britain's Asian empire (Afghanistan) and by diverting German manpower to the East. In the case of France, likely substitution took the form of an agreed specialization of forces in the event of war with Germany. The coefficient on the Anglo-French Entente is, however, insignificant.

The equation for Russia disaggregates spillins by allies. In Table 1, the negative and significant reaction to French military manpower is consistent both with free riding and the two powers' having no serious conflicts. After the Franco-Russian Alliance, a weak degree of complementarity is suggested as seen by the positive but in-

Table 1. GLS-AR(1) Estimates of the Demand for Military Activity for the Triple Entente Allies, 1880–1914

Independent Variables	Dependent Variables		
	UMIL	RMIL	FMIL
Constant	−814.3024[a] (−2.2073)	16,723.9805[a] (5.6685)	3,523.2422[a] (6.1736)
UINC	.0414[a] (2.5260)	—	—
RINC	—	.1745[a] (5.7609)	—
FINC	—	—	.0570[a] (2.1498)
LGAIMIL	.0868 (1.3421)	−.3063 (−1.3761)	.1288[a] (2.4978)
FRMILE	.0461 (1.6667)	—	—
UMILE	—	.6243[a] (1.9143)	.00013 (.0147)
FMILE	—	−1.9916[a] (−4.4751)	—
RMILE	—	—	−.0725[a] (−3.4141)
DFU • FE	−.0115 (−.6261)	—	—
DRU • RE	−.0195[a] (−2.0370)	—	—
DFR • FE	—	.0875 (1.2265)	—
DRU • UE	—	−.2153 (−1.5450)	—
DGR • GE	—	−.0901 (−1.0558)	—
DRI • IE	—	.2485 (1.6479)	—
DFU • UE	—	—	.0360 (1.2822)
DFR • RE	—	—	.0337[a] (2.7896)
DFI • IE	—	—	−.0159 (−.4780)
Rho estimate	.522	.492	.611
Adjusted R^2	.822	.846	.817

Note: t-statistics are in parentheses beneath coefficient estimates.

[a]Significant at the .10 level. This level corresponds to a t-statistic of 1.699 for the United Kingdom, 1.706 for Russia, and 1.703 for France.

significant coefficient of DFR • FE. Free riding is, however, still the net outcome.[5] The positive and significant response to British manpower is indicative of severe rivalry until the entente in 1907, after which the slope shift variable (DRU • UE) indicates some offsetting substitution. The agreement with Italy in 1909 had a positive and nearly significant effect on Russian manpower levels (DRI • IE); as all countries fortified for the approaching war, complementarity among forces may have been fostered. The negative reaction to the Triple Alliance threat is insignificant, as is the reaction to the Russo-German Treaty from 1879 to 1890.

For France, spillins are disaggregated for the United Kingdom and Russia, but

Table 2. GLS-AR(1) Estimates of the Demand for Military Activity for the Triple Alliance Allies, 1880–1914

Independent Variables	Dependent Variables		
	GMIL	AMIL	IMIL
Constant	667.2344 (.4798)	1,440.7637[a] (4.2365)	30.7636 (.0445)
GINC	.0616[a] (2.1376)	—	—
AINC	—	.0393[a] (4.2898)	—
IINC	—	—	.0748 (.7646)
LFUMIL	.1650 (.7752)	—	—
LRMIL	−.0903 (−.9341)	—	—
LFRUMIL	—	−.0340 (−.8402)	.0453 (.4994)
AIMILE	.2755[a] (2.2341)	—	—
GIMILE	—	.0421 (1.6930)	—
GMILE	—	—	.0852 (.9941)
AMILE	—	—	.1463 (.8385)
DGR • RE	−.0052 (−.1790)	—	—
DFI • FE	—	—	−.0441 (−1.1520)
DRI • RE	—	—	−.0075 (−.5951)
Rho estimate	.249	.611	.191
Adjusted R^2	.859	.805	.593

Note: t-statistics are in parentheses beneath coefficient estimates.

[a]Significant at the .10 level. This level corresponds to a t-statistic of 1.699 for Germany, 1.697 for Austria, and 1.701 for Italy.

the Triple Alliance threat is not. A strong positive response (Table 1) to the Triple Alliance reflects the fact that Franco-German enmity pervaded the entire period and dominated French military planning. Unexpectedly, the French response to UK military manpower is insignificant. France's response to Russia (like Russia's to France) is negative. Following the formation of the Franco-Russian alliance after 1893, free riding was attenuated somewhat, since the sign of the slope shift (DFR • RE) is positive of a value less than the coefficient on RMILE.

When France aligned with the United Kingdom and Russia, their forces were complementary against the Triple Alliance threat, as suggested by the signs on DFU • UE and DFR • RE. In the case of the United Kingdom, the entente resulted in agreements that required France to assume the primary responsibility for the land war with Germany. The data confirm that the French army increased markedly in size after 1910, while navy manpower remained static. Given the location of Germany between France and Russia, neither of these allies' forces could substitute for one another, thus explaining the strong positive coefficient on DFR • RE.

For Germany, the threat from Russia is separated from that from France and the United Kingdom because Russia was less of a rival than the latter two entente allies. In Table 2 the sign on LFUMIL is consistent with this rivalry, but the coefficient is insignificant. A negative (but insignificant and near-zero) coefficient is associated with the Russian threat. Similarly, the alliance with Russia until 1890 had no significant impact on German military activity. For most of the period, Russia and Germany were on friendly terms. The positive coefficient on AIMILE indicates that a complementarity existed between the forces of Germany and those of its allies.

Austria's positive and almost significant response to its allies' manpower (GIMILE) suggests that Austrian forces were complementary to those of the other allies (Table 2). This finding is probably due to Italy's being more of an enemy than an ally and to the inability readily to substitute German forces for Austrian in Austria's main theater of interest, the Balkans, owing to transportation difficulties. Austria responds insignificantly to the threat posed by the Triple Entente. Neither Britain nor France presented any direct military danger to Austria.

Given Italy's attempt to foster friendships in both alliances, it is not surprising that the Italian results in Table 2 are inconclusive. None of the coefficients are significant. Even though the results are poor, they are not inconsistent with the theory that makes predictions for "true" allies and enemies. In the Italian case, allies and enemies are impossible to distinguish, especially after the Franco-Italian neutrality agreement of 1900 and 1902.

Conclusion

Little evidence of free riding was found, except for France and Russia. Some free riding occurred in the latter half of the period as the alliances added members and cemented ties prior to World War I. The model used here could be extended to other areas of political inquiry. Many international problems (e.g., global pollution) could be explicated in the same fashion. In the American politics literature, interest groups have yet to be analyzed with the type of time series data that would provide a more accurate assessment of publicness problems than may be found in the usual static or cross-sectional tests.

Appendix: Income, Military Manpower and Alliance Variables

* = country designator, where U = United Kingdom, R = Russia, F = France, G = Germany, A = Austria-Hungary, and I = Italy.

*INC = real GNP in thousands of 1970 U.S. dollars.

*MIL = military manpower in hundreds of men, excluding reserves.

L*MIL = lagged military manpower threat, where LRMIL = Russia, LFUMIL = Anglo-French Entente, LFRUMIL = Triple Entente, and LGAIMIL = Triple Alliance.

*MILE = ally military manpower estimated from income of all alliance members, the lagged threat of the opposing alliance (LGAIMIL or LFRUMIL), and an intercept dummy for any alliance in which country * participated during the period.

D** • *E = military manpower slope shifts resulting from alliance entry or exit: alliance dummy (D** = 1 for entry, 0 for exit) times estimated manpower of entering or exiting party (*E), where DFU • FE, DFU • UE = Anglo-French Entente (0 for 1905 and prior years); DRU • UE, DRU • RE = Anglo-Russian Entente (0 for 1908 and prior years); DGR • RE, DGR • GE = Russo-German alliance (0 for 1892 and subsequent years); DRI • IE, DRI • RE = Russo-Italian agreement (0 for 1910 and prior years); DFI • IE, DFI • FE = Franco-Italian neutrality agreement (0 for 1901 and prior years); and DFR • FE, DFR • RE = Franco-Russian alliance (0 for 1894 and prior years).

Notes

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1. Impurity was mentioned by Olson and Zeckhauser (1966) and formally modeled by Murdoch and Sandler (1984).

2. In a longer unpublished version of this paper (available from the authors) we provide more historical details and examples of pre-1914 alliances.

3. Threat could be modeled as a subtraction from alliancewide protection, Z. Since we do not specifically model the arms race interaction between opposing alliances, our treatment of threat is sufficiently general for the purposes at hand—to derive a reduced-form estimating equation.

4. Sufficiency conditions are satisfied based on the assumptions invoked for the $f(\cdot)$, $g(\cdot)$, $g_j(\cdot)$, and $U(\cdot)$ functions. Thus, the FOCs are both necessary and sufficient for a maximum because the constraints are linear. If, in addition, the associated bordered Hessian determinant is positive definite, equation 8 follows from the FOCs via the implicit function theorem.

5. The net effect is found by adding together −1.9916 and .0875, since the equation is linear.

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John A. C. Conybeare is Professor of Political Science, University of Iowa, Iowa City, IA 52242.

Todd Sandler is Professor of Economics and Political Science, Iowa State University, Ames, IA 50011.