The role of aggregation technologies in the provision of supranational public goods: A reconsideration of NATO's strategies

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Abstract

Voluntary contributions to the provision of public goods do not necessarily follow a summation aggregation technology. The article investigates the alternative best-shot aggregation process and provides a comparison between efficient and equilibrium outcomes in the context of joint products in a supranational alliance. The application deals with NATO over the period 1955-2006 and evidences new breakpoints and aggregation technology assessments, which leads to a reconsideration of the alliance's strategy.

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1. Introduction

The provision of supranational public goods has become a subject of increasing concern for collective action. It may relate to transnational health programs, protection against environmental hazards, preservation of peace and security ...and it involves formal or informal supranational organizations which implement the decisions reached by their contributors (Sandler, 2006). Our paper follows this track as it is dedicated to the study and assessment of NATO's strategy from 1955 to 2006. NATO's strategy is interpreted here as the provision of supranational public goods, the nature and properties of which can vary during the period of study.

Members of NATO are sovereign states and they are modeled here as individual agents in a static and non cooperative voluntary provision game. It corresponds to the Bergstrom, Blume and Varian (1986) approach to public good provision. In this setting, contributions are aggregated by a summation technology, following the founding articles of Samuelson (1954, 1955). Early studies of NATO have used it, particularly the pioneering work of Olson and Zeckhauser (1966) which has triggered a vast literature surveyed by Sandler and Hartley (2001). Olson and Zeckhauser (1966) used a pure public good model which was later complemented with the joint product model of Sandler (1977). Broadly depicted, these set of studies has identified a first period (1949-1970) when the doctrine of "mutual assured destruction" (as it is formalized by NATO's directive MC48 in 1954) yielded the provision of a pure supranational public good. A second period is identified in reference to the new strategy elaborated in 1967, the “flexible response doctrine” (NATO’s directive MC14/3). The alliance now provides joint products. In both cases, sub-optimality of Nash equilibria is evidenced and it also triggers a heated debate on the so-called “exploitation hypothesis” by which small members of the alliance would free ride on the biggest contributor, namely the USA.

Intuitively, even if the previous theoretical setting is path-breaking, it may not be able to comprehend the variety of situations that can be faced when economic agents (either individuals or states) decide to engage into collective action. Admittedly, supranational public goods can be pure or can alternatively evidence joint products properties. Nevertheless, the technology of aggregation of contributions may not be as straightforward as that of summation. The situation may be so that the weakest contribution drags down the level of provided public good. Conversely, one agent may have such a prominent contribution that no other prevails, at least in static terms. In other words, technologies of aggregation of contributions matter. They do so in two respects.

First, from a theoretical viewpoint, Nash equilibria as well as conditions of Pareto efficiency are likely to differ from what they are in the standard summation setting. To our knowledge, the first systematic study of technologies of aggregation of contributions to public goods can be dated back to the seminal work of Hirshleifer (1983, 1985). Hirshleifer provides a thought-provoking intuitive analysis, using vivid examples and providing a diagrammatic illustration of the summation and weakest-link cases. Hirshleifer suggests a “moderate” under-provision in these two cases, which would be aggravated when the best-shot technology prevails (see also Cornes, 1993). Hirshleifer’s early results have recently been systematized by Cornes and Hartley (2007) in the context of the provision of a pure public good.

Second, alternative technologies of aggregation matter all the more in empirical terms that they may provide a much more accurate interpretation of facts. To our knowledge, there are not yet so many studies explicitly using such alternatives. Examples are for instance Burnett (2006) for a weakest-link interpretation of the collective fight against invasive species or Conybeare et al. (1994) who compare the explanatory of the weakest-link and best-shot technologies mainly in the case of pre-WWI alliances.

Our contribution to the theoretical and empirical landscape that has just been described is the following. In theoretical terms, we consider here the joint product model with alternative aggregation technologies. Earlier results have been provided by Sandler (1977) who studied efficiency and equilibrium in the summation case. In the present contribution, we provide an extension to the best-shot technology, which has not yet been (to our knowledge) previously implemented. As regards NATO's provision of supranational public goods, we use panel data for the first time (again, to our knowledge) over an extended horizon with an original data set (1955-2006). Contrary to standard analyses, we test unknown breakpoints for the competing technologies which are relevant in the NATO case, namely summation and best-shot. Testing a joint product demand function, the following results are evidenced. Best-shot rather than summation is relevant from 1955 to 1970. The year 1967 is rejected as the end of the period, contrary to what is usually assumed. Panel data estimations also confirm the summation technology from 1971 to 2006, also identifying an increase in strategic behaviors after 1990. We thus provide a reconsideration of NATO's strategies in the long run.

The article is organized as follows. Section 2 describes the theoretical framework. Section 3 presents the empirical results, followed by concluding comments and discussion in section 4.

2. Provision of joint products in an alliance under summation or best-shot technologies

We first present a model of joint products in an alliance, allowing summation and best-shot technologies (section 2.1). We then move on to the efficiency conditions (section 2.2) and finally give the equilibrium characteristics in both cases (section 2.3).

2.1. Joint products under summation or best-shot

Consider an alliance consisting of countries $i = 1, \cdots, n$. Membership implies contributing an amount g_i to the supranational public good G provided by the alliance. Allies have initial endowments y_i and their utility functions comprise the consumption of the private good in quantity x_i, this private good being taken as numéraire. The expression of utility functions then depends on the type of public good provided by the alliance. In the Olson and Zeckhauser (1966) framework, it is a pure public good G, so that $u_i = u_i(x_i, G)$. With the joint product approach suggested by Sandler (1977) and adopted here, the ally's global military activity q_i comprehends a contribution $g_i = \beta q_i$ to the alliance-wide deterrence and an ally-specific local public good $z_i = \alpha q_i$. To give an illustration, GDP y_i of the allied country is used for the private consumption x_i of its citizens (and possibly for the provision of non-military national public goods), for conventional and tactical weapons z_i aiming at the direct protection of its territorial and external interests, and for contributing with g_i to the stockpile of strategic weapons on which the alliance's defense policy is built. In the joint product case, the utility function is thus $u_i = u_i(x_i, z_i, G)$.

Following Cornes and Sandler (1996), the aggregation technologies of contribution can be synthesized by

(1) $$G = G(g_1, \cdots, g_i, \cdots, g_n) = \delta\left\{\frac{1}{n}\sum_{i=1}^{n} g_i^{v}\right\}^{1/v}$$

Specific values of parameters δ and v define three technologies. Summation is such that

(2) $$\delta = n \quad v = 1 \quad \Longrightarrow \quad G(g_1, \cdots, g_i, \cdots, g_n) = \sum_{i=1}^{n} g_i$$

Weakest link is given by

(3) $$\delta = 1 \quad v \to -\infty \quad \Longrightarrow \quad G(g_1, \cdots, g_i, \cdots, g_n) \to \min_i (g_1, \cdots, g_i, \cdots, g_n)$$

The smallest contribution sets the aggregate level of public good.
Best shot is defined by

(4) $$\delta = 1 \quad v \to +\infty \quad \Longrightarrow \quad G(g_1, \cdots, g_i, \cdots, g_n) \to \max_i (g_1, \cdots, g_i, \cdots, g_n)$$

The largest contribution defines the aggregate level of public good.

In the joint product case, the functional form of the aggregation technology becomes

(5) $$G = G(g_1, \cdots, g_i, \cdots, g_n) = \beta\delta\left\{\frac{1}{n}\sum_{i=1}^{n} q_i^{v}\right\}^{1/v}$$

2.2. Efficiency conditions under summation or best-shot

We derive the conditions of Pareto efficiency under the alternative aggregation technologies. The Pareto program for a joint product model is

(6) $$\max_{x_i, q_i; i=1,\dots,n} \quad u_1 = u_1(x_1, z_1, G(g_1, \cdots, g_i, \cdots, g_n))$$

$$\textit{subject to} \quad u_i = \bar{u}_i \qquad i = 2, \cdots, n \quad \textit{and} \quad \sum_{i=1}^{n} x_i + \sum_{i=1}^{n} g_i = \sum_{i=1}^{n} y_i$$

$$\textit{with}$$

$$G = G(g_1, \cdots, g_i, \cdots, g_n) = \delta \left\{ \frac{1}{n} \sum_{i=1}^{n} g_i^{\upsilon} \right\}^{1/\upsilon}$$

$$and \qquad z_i = \alpha q_i \qquad\qquad g_i = \beta q_i \qquad\qquad i = 1, \cdots, n$$

The general form of the first order necessary conditions is

(7) $\alpha MRS_{z_1 x_1} + \frac{\partial G}{\partial g_1} \beta \sum_{i=1}^{n} MRS_{G, x_i} = 1$

(8) $\alpha MRS_{z_j x_j} + \frac{\partial G}{\partial g_j} \beta \sum_{i=1}^{n} MRS_{G x_i} = 1 \qquad j = 2, \cdots, n$

From which one can isolate and develop:

(9) $\frac{\partial G}{\partial g_j} = \delta \left[\frac{1}{n}\right]^{\frac{1}{\upsilon}} \left[\frac{1}{1 + \left(\frac{g_z}{g_j}\right)^{\upsilon} + \cdots + \left(\frac{g_n}{g_j}\right)^{\upsilon}} \right]^{1 - \frac{1}{\upsilon}}$

With a summation technology, we have $\delta = n$ and $\upsilon = 1$ which implies that $\frac{\partial G}{\partial g_j} = 1$.

We thus reach the standard efficiency condition:

(10) $\alpha MRS_{z_j x_j} + \beta \sum_{i=1}^{n} MRS_{G x_i} = 1 \qquad j = 1, \cdots, n$

With a best-shot technology, parameters are such that $\delta = 1$ and $\upsilon \rightarrow +\infty$. Equation (9) becomes:

(11) $\frac{\partial G}{\partial g_j} \rightarrow \left[\frac{1}{1 + \left(\frac{g_z}{g_j}\right)^{+\infty} + \cdots + \left(\frac{g_n}{g_j}\right)^{+\infty}} \right]$

If $g_j = g_{max}$, then $\frac{\partial G}{\partial g_{max}} \rightarrow 1$. Otherwise, if $g_j \neq g_{max}$, then $\frac{\partial G}{\partial g_j} \rightarrow 0$. We thus obtain:

(12) $\alpha MRS_{z_{max} x_{max}} + \beta \sum_{i=1}^{n} MRS_{G x_i} = 1 \quad for\ the\ best\ shot$

(13) $\alpha MRS_{z_j x_j} = 1 \quad for\ the\ other\ contributors$

In this case, member countries other than the best-shot do have some military activity, but they do not contribute to the alliance-wide provision of deterrence. This is to our knowledge the first formal demonstration of this result.

2.3. Equilibrium conditions

The aim is to derive the characteristics of the Nash equilibrium of a voluntary contribution game and compare them with those of the Pareto program. First, in the case of a summation aggregation technology, with p the unit price of defense activity (Cornes and Sandler, 1984), the Nash program of a given contributor is:

(14) $$\max_{x_i, q_i; i=1,\dots,n} \quad u_i = u_i(x_i, z_i, G))$$
$$\textit{subject to} \quad x_i + pq_i = y_i$$
$$\textit{with}$$
$$G = G(g_1, \cdots, g_i, \cdots, g_n) = \sum_{i=1}^{n} g_i$$
$$\textit{and} \qquad z_i = \alpha q_i \qquad g_i = \beta q_i$$

The first order conditions are such that:

(15) $$\alpha MRS_{z_i x_i} + \beta MRS_{G x_i} = p$$

(16) $$x_i + pq_i = y_i$$

The formal proof of the existence and unicity (the latter under an assumption of normality) is recent (Kotchen, 2007). The inefficiency of the voluntary contributions appears immediately.

We then move on to an original treatment of the best-shot case, in which the Nash program of a given member state is:

(17) $$\max_{x_i, q_i; i=1,\dots,n} \quad u_i = u_i(x_i, z_i, G))$$
$$\textit{subject to} \quad x_i + pq_i = y_i$$
$$\textit{with}$$
$$G = G(g_1, \cdots, g_i, \cdots, g_n) = \left\{\frac{1}{n}\sum_{i=1}^{n} g_i^{\upsilon}\right\}^{\frac{1}{\upsilon}} \qquad \upsilon \to +\infty$$
$$\textit{and} \qquad z_i = \alpha q_i \qquad g_i = \beta q_i$$

The first order conditions are:

(18) $$\alpha MRS_{z_i x_i} + \frac{\partial G}{\partial g_i} \beta MRS_{G,x_i} = p$$

(19) $$x_i + pq_i = y_i$$

Change the index of equation (11) so that:

(20) $$\frac{\partial G}{\partial g_i} \rightarrow \left[\frac{1}{1+\left(\frac{g_2}{g_i}\right)^{+\infty} + \cdots + \left(\frac{g_n}{g_i}\right)^{+\infty}} \right]$$

If $g_i < g_j \ \forall j$, then $\frac{\partial G}{\partial g_i} \rightarrow 0$. In this case:

(21) $$\alpha MRS_{z_i x_i} = p$$

(22) $$x_i + pq_i = y_i$$

If $g_i > g_j \ \forall j$, then $\frac{\partial G}{\partial g_i} \rightarrow 1$. Then:

(23) $$\alpha MRS_{z_i x_i} + \beta MRS_{G,x_i} = p$$

(24) $$x_i + pq_i = y_i$$

We obtain symmetrical results for all agents. Equilibrium conditions are thus:

(25) $$\alpha MRS_{z_i x_i} = p \quad for\ g_i < g_j$$

(26) $$\alpha MRS_{z_i x_i} + \beta MRS_{G,x_i} = p \quad for\ g_i > g_j$$

Here again, voluntary contributions are inefficient.

Existence and unicity will be discussed using numerical simulations. These simulations are already implemented and will be detailed in the final conference version of the paper.

3. Application to NATO

The final conference version of the paper will provide more details about the econometric methods and results as well as an introductory survey of existing empirical studies.

3.1. Presentation and preliminary analysis of the data set

The study goes over 1955-2006 for fourteen countries of the alliance[i]. The first years (1949-1954) are not included since they are mostly a set-up period. 1955 also marks the entry of Germany in the alliance. The fourteen countries are members over the whole study period. Four variables are considered here (see table 1 for more details).

(Table 1 about here)

GDP_i is the income of country i. DEF_i represents defense expenditures. The other two variables specifically relate the theoretical model to the estimations. $SUM_i = \sum_{j \neq i} DEF_j$ consists of the defense expenditures of the allies of country i. $BS_i = \max_{j \neq i} DEF_j$ defines the best-shot ally, with $BS_{Best-shot} = 0$. Throughout the period, the USA is the best-shot. Standard and more advanced tests (like Pesaran, 2003) regarding possible unit roots are implemented. They all conclude that the presence of unit roots for all series cannot be rejected.

3.2. Econometric method

The economic objective is to identify possible evolutions in the aggregation technologies of contributions to the provision of a defense supranational public good by NATO. We thus consider the behavior of the alliance as a whole, and not country by country. The econometric method that is used here is the Panel Corrected Standard Errors (PCSE) suggested by Beck and Katz (1995). This method minimizes the fallacious regression problem. We allow unknown breaks as well as unknown periodization (i.e. the number of allowed breaks is unknown). The dependent variables are the defense expenditures DEF_i of the allies over the whole period. To our knowledge, there is at the moment no available method for panel data that would comprehend both a variable number of breaks and a change in one of the explanatory variables (here, the aggregation technology). The testing strategy is thus step by step, with firstly no allowed break; secondly allowed breaks with successive technologies (summation then best-shot or vice versa); the objective of this second step is let emerge relevant breakpoints. Thirdly, using the previously identified dates, the last step uses a battery of J tests with fixed breakpoints and all possible combinations of technologies of aggregation over time.

3.3. Results

Recall that the first step of the econometric method consists in allowing no break and in testing the validity of the competing aggregation technologies. The two estimated models are panel data with fixed effects and homogenous coefficients (endogeneity is cared for with lagged variables):

(27) $$DEF_{i,t} = \alpha_{1,i} + \beta_1 GDP_{i,t} + \gamma_1 SUM_{i,t-1} + \varepsilon_{i,t}$$

(28) $$DEF_{i,t} = \alpha_{2,i} + \beta_2 GDP_{i,t} + \gamma_2 BS_{i,t-1} + \varepsilon_{i,t}$$

Both models present autocorrelation and heteroscedasticity. PCSE estimations are carried out and they bring a surprising result: summation and best shot variables are indeed not significant (in the existing studies, summation at least is always significant). The problem is not that of a fallacious regression since parameters are not significant. The formalization should then be enriched.

This leads us to the second step, namely the possibility of successive aggregation technologies (summation then best-shot or best-shot then summation). In order to introduce breakpoint, we define the following variables:

(29) $$SUM1_{i,t-1} = date_K \times SUM_{i,t-1}$$

(30) $$SUM2_{i,t-1} = (1 - date_K) \times SUM_{i,t-1}$$

(31) $$BS1_{i,t-1} = date_K \times BS_{i,t-1}$$

(32) $$BS2_{i,t-1} = (1 - date_K) \times BS_{i,t-1}$$

The dummy variable $date_K$ take value 1 from 1955 until date K and value 0 afterwards. Investigations begin with possible time breaks for each technology considered independently:

(33) $$DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1\, SUM1_{i,t-1} + \delta_2\, SUM2_{i,t-1}$$

(34) $$DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1\, BS1_{i,t-1} + \delta_2\, BS2_{i,t-1}$$

No significant breakpoint (not even the standard 1967 date) appears in either case. We then mix the two technologies in the following sequences:

(35) $$DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1\, BS1_{i,t-1} + \delta_2\, SUM2_{i,t-1}$$

(36) $$DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1\, SUM1_{i,t-1} + \delta_2\, BS2_{i,t-1}$$

Surprisingly, both estimations identify two breakpoints in 1970 and 1990. There would thus be a three period model with alternation of technologies. We keep those dates as breakup points for the next investigations.

The third step indeed will consider these fixed dates and will allow for technology changes from one period to another. Breakpoints are extended accordingly:

(37) $$SUM1_{i,t-1} = date_{1970} \times SUM_{i,t-1}$$

(38) $$SUM2_{i,t-1} = (date_{1990} - date_{1970}) \times SUM_{i,t-1}$$

(39) $$SUM3_{i,t-1} = (1 - date_{1990}) \times SUM_{i,t-1}$$

(40) $$BS1_{i,t-1} = date_{1970} \times BS_{i,t-1}$$

(41) $$BS2_{i,t-1} = (date_{1990} - date_{1970}) \times BS_{i,t-1}$$

(42) $$BS3_{i,t-1} = (1 - date_{1990}) \times BS_{i,t-1}$$

The three periods and the two technologies bring about eight different models providing all possible combinations of technologies over time. The competing models are systematically evaluated against the seven others.

The complete J tests will be provided in an appendix in the final conference version of the paper.

The best performer is the following:

(43) $$DEF_{i,t} = \alpha_i + \beta GDP_{i,t} \;+\; \delta_1\, BS1_{i,t-1} + \delta_2\, SUM2_{i,t-1} + \delta_3\, SUM3_{i,t-1}$$

Estimated parameters are:

Variables	Estimated coefficients*
GDP	0.5384
$BS1$	-0.0163
$SUM2$	-0.0133
$SUM3$	-0.0175

All coefficients significant at .10 level

NATO's strategy is thus first characterized by a best-shot situation from 1955 to 1970; from this date onwards, a summation technology prevails with an increase in strategic behavior after 1990.

4. Discussion of results and conclusion

To be completed for the final conference version of the paper.

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Table 1: Description of variables

1955-2006	Description (Log of…)	Unit	Reference year	Source
GDP_i	Gross Domestic Product	Million USD	2000	IMF 2008*
DEF_i	Defense Expenditures	Million USD	2000	NATO 2009
$SUM_i = \sum_{j \neq i} DEF_j$	Other allies cumulated defense efforts	Million USD	2000	NATO 2009
$BS_i = \max_{j \neq i} DEF_j$	Best-shot ally defense expenditures	Million USD	2000	NATO 2009

*Greece 1955-1966: OECD

[i] Countries included in the study are Belgium, Canada, Denmark, France, Germany, Greece, Italy, Luxemburg, the Netherlands, Norway, Portugal, Turkey, United Kingdom, and United States of America. Greece stepped out from 1974 to 1980 but is treated as unofficial member during this period.