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 the corresponding Nash equilibrium conditions for allies 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. We find that a best-shot technology prevails from 1955 to 1970. Afterwards, summation of contributions becomes the aggregation technology of the alliance, with increased strategic behavior after 1990.

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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 and 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 a supranational public good whose nature and properties 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 game of voluntary contributions (Warr 1983; Cornes and Sandler 1984; Bergstrom et al. 1986). In this setting, contributions to the supranational public good are usually aggregated by a summation technology, following the founding articles of Samuelson (1954, 1955). 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 that was later complemented with the joint product model of Sandler (1977). This literature has identified a first period (1949-1967) when the doctrine of "mutual assured destruction" (as it is formalized by NATO's directive MC48 in 1954) yields a pure supranational public good. A second period begins with 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 United States.

From 1991 onwards, the "crisis management doctrine" prevails. The exploitation debate somewhat fades away, but new challenges arise. Europe and the world's security and stability amount to purely public benefits (Sandler and Hartley 2001), which increases the share of pure public outputs in NATO's activities as well as free-riding opportunities.

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. In particular, the technology of aggregation of contributions may not always 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, the technology of aggregation of contributions matters. It does so in two respects.

First, from a theoretical viewpoint, Nash equilibrium conditions are likely to differ from what they are in the standard summation setting. The 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 (see also Cornes 1993). The early results of Hirshleifer have recently been systematized by Cornes and Hartley (2007) in the context of the provision of a pure public good (for an approach with incomplete information see also Xu 2001).

Second, in empirical terms, alternative technologies of aggregation matter all the more that they may provide a much more accurate illumination of facts. There are very few studies explicitly using such alternatives. A good example is for instance Conybeare et al. (1994) who compare the explanatory power 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. Most if not all NATO members have always kept their own "private" defense agenda, with for instance regional or colonial interests or internal security constraints.

Furthermore, national conventional forces can be deployed along an alliance's perimeter or they can join combined task forces. The joint product model thus seems to more adequately fit the objectives and constraints of the allies.

Nash equilibrium conditions have been provided by Sandler (1977) in the summation case and by Conybeare et al. (1994) in the best-shot case. We provide a concise presentation of both. In empirical terms, we use panel data for the first time (to our knowledge) over an extended horizon (1955-2006). Contrary to Gadea et al. (2004) who test unknown breakpoints with a summation technology in a time series framework, we test competing technologies that are relevant in the NATO case, namely summation and best-shot, with unknown breakpoints in a panel data framework. The case of a weakest link could have been envisaged, at least in theoretical terms. However, the empirical framework of deterrence, whether or not mitigated by potential conventional conflict, does not plead in favor of this aggregation technology. Deterrence is indeed characterized by a global defense strategy as opposed to what Hirshleifer (1983: 372) labels a "linear" situation where each member of the alliance is responsible for one link of a chain. In other historical circumstances, this weakest-link situation has been proved relevant. For instance, Conybeare et al. (1994) and Conybeare and Sandler (1990) have shown that the United Kingdom was the weakest-link of the Triple Entente in the World War I conflict. The Cold War context is quite different.

We find that best-shot rather than summation is relevant from 1955 to 1970. Year 1967 is often regarded as the end of the first period (Sandler and Forbes 1980; Oneal and Elrod 1989; Khanna and Sandler 1996). Our estimations thus reject this date.[1] They confirm the summation technology from 1971 to 2006, but they identify an increase in strategic behaviors after 1990. Summation can indeed be associated with the opportunistic behavior of allies intending to shift the defense burden on the others. This kind of "free-riding" intensifies after

[1] Admittedly, Sandler and Murdoch (2000) do not consider the 1967 date as a study result but use it as an institutional landmark. Others do not take it as given in their econometric investigations (for instance Gadea et al. 2004)

1990. All these results provide a significant 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 or best-shot technologies (section 2.1). We then specify the Nash equilibrium conditions in both cases (section 2.2).

2.1. Joint products under summation or best-shot

Consider an alliance consisting of countries $i = 1, \ldots, n$. Membership implies contributing to the supranational public good G provided by the alliance. Allies have initial endowments y_i and their utility functions comprise the consumption of a numéraire in quantity x_i. The expression of utility functions then depends on the type of public good provided by the alliance. In the Olson and Zeckhauser (1966) framework, G is a pure public good, 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 to the alliance-wide deterrence G and an ally-specific local public good. To give an illustration, GDP y_i of the allied country is in part used for the consumption x_i of its citizens, possibly including the provision of non-military national public goods. The complement q_i is used for conventional and tactical weapons aiming at the direct protection of its national interests, and for contributing to the stockpile of strategic weapons G on which the alliance's defense policy is built. In the joint product case, the utility function is thus $u_i = u_i(x_i, q_i, G)$.

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

$$G = G(q_1, \ldots, q_i, \ldots, q_n) = \phi \left(\frac{1}{n} \sum_{i=1}^{n} q_i^{\nu} \right)^{\frac{1}{\nu}} \tag{1}$$

Different values of parameters ϕ and ν define specific technologies.[2] Among them, summation is such that

$$\phi = n \textit{ and } \nu = 1 \Rightarrow G = G(q_1, \ldots, q_i, \ldots, q_n) = \sum_{i=1}^{n} q_i \tag{2}$$

Best shot is defined by

$$\phi = 1 \textit{ and } \nu = +\infty \Rightarrow G = G(q_1, \ldots, q_i, \ldots, q_n) \to \max_i (q_1, \ldots, q_i, \ldots, q_n) \tag{3}$$

The largest contribution defines the aggregate level of public good.

2.2. Nash equilibrium conditions

First, we consider the case of a summation aggregation technology (Cornes and Sandler 1984). With p the unit price of defense activity and the unit price of x_i set at 1, the Nash program of a given contributor i is

$$\max_{x_i, q_i; i=1,\ldots,n} u_i = u_i(x_i, q_i, G) \text{ subject to } x_i + pq_i = y_i \tag{4}$$

where $G = G(q_1, \ldots, q_i, \ldots, q_n) = \sum_{i=1}^{n} q_i$

[2] We do not consider the weakest link, which is given by

$$\phi = 1 \textit{ and } \nu = -\infty \Rightarrow G = G(q_1, \ldots, q_i, \ldots, q_n) \to \min_i (q_1, \ldots, q_i, \ldots, q_n)$$

The smallest contribution sets the aggregate level of public good.

Using the first order conditions, we get

$$\frac{\dfrac{\partial u_i\left(y_i - pq_i, q_i, G\right)}{\partial q_i}}{\dfrac{\partial u_i\left(y_i - pq_i, q_i, G\right)}{\partial x_i}} + \frac{\dfrac{\partial u_i\left(y_i - pq_i, q_i, G\right)}{\partial G}}{\dfrac{\partial u_i\left(y_i - pq_i, q_i, G\right)}{\partial x_i}} = p \tag{5}$$

The Nash equilibrium condition for country i can thus be expressed as

$$q_i = f_i\left(G_{-i}, y_i, p\right) \tag{6}$$

where G_{-i} is the total defense expenditures of the alliance minus those of country i.

We then move on to the best-shot case (Conybeare et al. 1994), for which the Nash program of a given member state is the same as 4 but where $G = G(q_1, \ldots, q_i, \ldots, q_n) = \left(\frac{1}{n}\sum_{i=1}^{n} q_i^{\nu}\right)^{\frac{1}{\nu}}$ and $\nu = +\infty$.

Using the first order conditions we obtain

$$\frac{\dfrac{\partial u_i\left(y_i - pq_i, q_i, G\right)}{\partial q_i}}{\dfrac{\partial u_i\left(y_i - pq_i, q_i, G\right)}{\partial x_i}} + \frac{\dfrac{\partial u_i\left(y_i - pq_i, q_i, G\right)}{\partial G}}{\dfrac{\partial u_i\left(y_i - pq_i, q_i, G\right)}{\partial x_i}} \frac{\partial G}{\partial q_i} = p \tag{7}$$

Deriving equation 1 with respect to q_i gives

$$\frac{\partial G}{\partial q_i} \rightarrow \left(\frac{1}{n}\right)^{\frac{1}{\nu}} \left(\frac{1}{\left(\dfrac{q_1}{q_i}\right)^{\nu} + \ldots + 1 + \ldots + \left(\dfrac{q_n}{q_i}\right)^{\nu}}\right)^{1-\frac{1}{\nu}} \tag{8}$$

For a best-shot technology, $\nu = +\infty$. Equation 8 becomes

$$\frac{\partial G}{\partial q_i} \rightarrow \left(\frac{1}{\left(\dfrac{q_1}{q_i}\right)^{\infty} + \ldots + 1 + \ldots + \left(\dfrac{q_n}{q_i}\right)^{\infty}}\right) \tag{9}$$

If $q_i = q_{max}$, then $\frac{\partial G}{\partial q_{max}} \to 1$. Otherwise, if $q_i \neq q_{max}$, then $\frac{\partial G}{\partial q_i} \to 0$.

If $q_i \neq q_{max}$, country i is not the best-shot ally. Using equation 7, its Nash equilibrium condition can be written as

$$q_i = f_i\left(G_{max}, y_i, p\right) \tag{10}$$

where G_{max} represents the defense expenditures of the best-shot ally.

If $q_i = q_{max}$, country i is the best-shot ally. We proceed in a similar way to obtain its Nash equilibrium condition

$$q_{max} = f_{max}\left(y_{max}, p\right) \tag{11}$$

We now propose to apply the previous framework to the assessment of NATO's policies over the last six decades.

3. Application to NATO

3.1. Presentation and preliminary analysis of the data set

The study goes over 1955-2006. The first years of NATO (1949-1954) are not included since they are mostly a set-up period. Year 1955 also marks the entry of Germany in the alliance. Countries included in the study are Belgium, Canada, Denmark, France, Germany, Greece, Italy, Luxemburg, the Netherlands, Norway, Portugal, Turkey, the United Kingdom, and the United States of America. Greece stepped out from 1974 to 1980 but is treated as unofficial member during this period. We then have a balanced panel data over a long period of time (52 years). Four variables are considered here (see table 1 for more details).

GDP_i is the income of country i. DEF_i represents its 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. $BS_i = \max_{j \neq i} DEF_i$ defines the best-shot ally, with $BS_{best-shot} = 0$. Throughout the period, the United States is the best-

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
$BS_i = \max_{j \neq i} DEF_i$	Best-shot ally defense expenditures	Million USD	2000	NATO 2009

* Greece 1955-1966: OECD.

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.

The likely problem of endogeneity is dealt with by using lagged variables. Difficulties associated with finding relevant instrumental variables plead in favor of lags in SUM and BS (Wooldridge 2002, p. 104). Murdoch and Sandler (1984), Smith (1989) and Hansen et al. (1990) proceed in a similar way.

3.2. Econometric method

The objective is to identify possible evolutions in the aggregation technologies of contributions to the provision by NATO of a defense supranational public good. 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 with allowed breaks for successive technologies (summation then best-shot or vice versa); the objective of this second step is to let emerge relevant breakpoints. Thirdly, using the previously identified dates, the last step runs a battery of J tests with fixed breakpoints and all possible combinations of technologies of aggregation over time to identify the best performing model.

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 homogeneous coefficients (endogeneity is cared for with lagged variables as explained previously):

$$DEF_{i,t} = \alpha_{1,i} + \beta_1 GDP_{i,t} + \gamma_1 SUM_{i,t-1} + \varepsilon_{i,t} \quad (12)$$

$$DEF_{i,t} = \alpha_{2,i} + \beta_2 GDP_{i,t} + \gamma_2 BS_{i,t-1} + \varepsilon_{i,t} \quad (13)$$

Equation 12 is country i's reaction function in presence of a summation technology as suggested by equation 6. Equation 13 displays the reaction function of country i when the technology is a best-shot according to equations 10 and 11. Both models present autocorrelation and heteroscedasticity. We then estimate fixed effects OLS models using panel corrected standard errors (PCSE) as suggested by Beck and Katz (1995). Our estimations bring a surprising result: summation and best shot variables are indeed not significant. The hypothesis of a single and continuous technology over the whole period can then be rejected. 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 breakpoints, we define the following variables:

$$SUM1_{i,t-1} = (date_K)(SUM_{i,t-1}) \tag{14}$$

$$SUM2_{i,t-1} = (1 - date_K)(SUM_{i,t-1}) \tag{15}$$

$$BS1_{i,t-1} = (date_K)(BS_{i,t-1}) \tag{16}$$

$$BS2_{i,t-1} = (1 - date_K)(BS_{i,t-1}) \tag{17}$$

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

$$DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 SUM1_{i,t-1} + \delta_2 SUM2_{i,t-1} \tag{18}$$

$$DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 BS1_{i,t-1} + \delta_2 BS2_{i,t-1} \tag{19}$$

This new specification does not improve our results: in all these models we find that variables $SUM1$, $SUM2$, $BS1$ and $BS2$ are not significant for all periods whichever time break is tested. At conventional levels no significant breakpoints appear in either case, not even the standard 1967 date. We then mix the two technologies in the following sequences:

$$DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 BS1_{i,t-1} + \delta_2 SUM2_{i,t-1} \tag{20}$$

$$DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 SUM1_{i,t-1} + \delta_2 BS2_{i,t-1} \tag{21}$$

Both estimations identify two breakpoints in 1970 and 1990. Estimations of equation 20 yield a model where $BS1$ and $SUM2$ are significant with a break in 1970 and another in 1990. Estimations of equation 21 also provide a model where $SUM1$ and $BS2$ are significant, with the same time break as with equation 20 (see tables 2 and 3). From those contradictory results, technology shifts do appear in 1970 and 1950, but at this stage those shifts cannot be sorted out.

Table 2. Estimation of time breaks for equation 20.

	GDP	BS1	SUM2		GDP	BS1	SUM2
Model 1955	0.475***	(dropped)	0.017	Model 1981	0.468***	0.003	0.005
Model 1956	0.480***	0.001	0.001	Model 1982	0.485***	0.001	0.001
Model 1957	0.493***	0.004	-0.000	Model 1983	0.487***	-0.001	-0.001
Model 1958	0.470***	-0.006	-0.003	Model 1984	0.493***	0.003	0.002
Model 1959	0.491***	-0.002	-0.004	Model 1985	0.495***	0.002	0.001
Model 1960	0.457***	-0.003	0.002	Model 1986	0.497***	-0.005	-0.004
Model 1961	0.446***	-0.003	0.003	Model 1987	0.513***	-0.004	-0.006
Model 1962	0.485***	-0.004	-0.004	Model 1988	0.519***	-0.003	-0.005
Model 1963	0.471***	-0.008	-0.006	Model 1989	0.518***	-0.006	-0.007
Model 1964	0.484***	-0.004	-0.004	**Model 1990**	**0.533*** **	**-0.010***	**-0.013** **
Model 1965	0.472***	0.009	0.010*	Model 1991	0.537***	0.001	-0.003
Model 1966	0.461***	0.005	0.008	Model 1992	0.547***	-0.005	-0.010*
Model 1967	0.484***	-0.001	-0.001	Model 1993	0.547***	-0.007	-0.011*
Model 1968	0.498***	-0.004	-0.006	Model 1994	0.555***	-0.004	-0.010*
Model 1969	0.477***	-0.008	-0.007	Model 1995	0.538***	-0.007	-0.010*
Model 1970	**0.472*** **	**-0.013** **	**-0.011***	Model 1996	0.533***	-0.003	-0.006
Model 1971	0.472***	-0.005	-0.003	Model 1997	0.522***	-0.005	-0.006
Model 1972	0.494***	-0.007	-0.008	Model 1998	0.517***	-0.002	-0.004
Model 1973	0.457***	-0.006	-0.001	Model 1999	0.519***	0.004	0.000
Model 1974	0.459***	-0.009	-0.004	Model 2000	0.508***	0.000	-0.001
Model 1975	0.491***	-0.007	-0.008	Model 2001	0.518***	0.012*	0.007
Model 1976	0.475***	-0.001	-0.000	Model 2002	0.508***	0.012*	0.008
Model 1977	0.476***	-0.004	-0.003	Model 2003	0.505***	0.007	0.005
Model 1978	0.483***	-0.001	-0.001	Model 2004	0.502***	0.004	0.002
Model 1979	0.472***	0.001	0.003	Model 2005	0.504***	-0.001	-0.003
Model 1980	0.466***	0.000	0.003	Model 2006	0.478***	-0.001	(dropped)

(*), (**), (***): respectively significant at 10%, 5% and 1% level.

Table 3. Estimation of time breaks for equation 21.

	GDP	SUM1	BS2		GDP	SUM1	BS2
Model 1955	0.478***	(dropped)	-0.001	Model 1981	0.470***	-0.006	-0.003
Model 1956	0.481***	-0.001	-0.001	Model 1982	0.486***	-0.000	-0.001
Model 1957	0.494***	0.001	-0.003	Model 1983	0.487***	0.001	0.001
Model 1958	0.469***	0.003	0.006	Model 1984	0.495***	-0.002	-0.003
Model 1959	0.490***	0.004	0.003	Model 1985	0.497***	-0.001	-0.002
Model 1960	0.456***	-0.002	0.003	Model 1986	0.496***	0.004	0.005
Model 1961	0.446***	-0.004	0.002	Model 1987	0.512***	0.006	0.004
Model 1962	0.484***	0.004	0.004	Model 1988	0.517***	0.005	0.003
Model 1963	0.469***	0.006	0.008	Model 1989	0.514***	0.007	0.006
Model 1964	0.483***	0.004	0.004	**Model 1990**	**0.526*** **	**0.013** **	**0.010***
Model 1965	0.476***	-0.010*	-0.009	Model 1991	0.535***	0.002	-0.002
Model 1966	0.463***	-0.009	-0.006	Model 1992	0.541***	0.009*	0.005
Model 1967	0.484***	0.001	0.001	Model 1993	0.540***	0.010*	0.006
Model 1968	0.497***	0.006	0.004	Model 1994	0.549***	0.009	0.003
Model 1969	0.474***	0.007	0.009	Model 1995	0.532***	0.009	0.006
Model 1970	**0.467*** **	**0.011***	**0.014** **	Model 1996	0.530***	0.005	0.002
Model 1971	0.470***	0.004	0.006	Model 1997	0.519***	0.006	0.005
Model 1972	0.492***	0.008	0.007	Model 1998	0.516***	0.004	0.002
Model 1973	0.455***	0.002	0.007	Model 1999	0.519***	-0.000	-0.004
Model 1974	0.457***	0.004	0.009	Model 2000	0.508***	0.001	0.000
Model 1975	0.489***	0.008	0.007	Model 2001	0.521***	-0.006	-0.012*
Model 1976	0.475***	0.000	0.001	Model 2002	0.511***	-0.007	-0.011*
Model 1977	0.475***	0.003	0.004	Model 2003	0.506***	-0.004	-0.006
Model 1978	0.483***	0.001	0.001	Model 2004	0.502***	-0.002	-0.004
Model 1979	0.473***	-0.003	-0.001	Model 2005	0.503***	0.003	0.001
Model 1980	0.467***	-0.003	-0.000	Model 2006	0.475***	0.017	(dropped)

(*), (**), (***): respectively significant at 10%, 5% and 1% level.

There would be a three period model, 1955-1970, 1971-1990 and 1991-2006, with possible 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:

$$SUM1_{i,t-1} = (date_{1970})\,(SUM_{i,t-1}) \tag{22}$$

$$SUM2_{i,t-1} = (date_{1990} - date_{1970})\,(SUM_{i,t-1}) \tag{23}$$

$$SUM3_{i,t-1} = (1 - date_{1990})\,(SUM_{i,t-1}) \tag{24}$$

$$BS1_{i,t-1} = (date_{1970})\,(BS_{i,t-1}) \tag{25}$$

$$BS2_{i,t-1} = (date_{1990} - date_{1970})\,(BS_{i,t-1}) \tag{26}$$

$$BS3_{i,t-1} = (1 - date_{1990})\,(BS_{i,t-1}) \tag{27}$$

$SUM1$, $SUM2$ and $SUM3$ correspond to the summation technology respectively before 1970, from 1971 to 1990, and after 1990. The same periods of time and the best-shot variables are denoted by $BS1$, $BS2$ and $BS3$. Consequently, the three periods and the two technologies bring about eight different models providing all possible combinations of technologies over time.

$$Model\ 1: \quad DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 SUM1_{i,t-1} + \delta_2 SUM2_{i,t-1} + \delta_3 SUM3_{i,t-1}$$

$$Model\ 2: \quad DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 SUM1_{i,t-1} + \delta_2 SUM2_{i,t-1} + \delta_3 BS3_{i,t-1}$$

$$Model\ 3: \quad DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 SUM1_{i,t-1} + \delta_2 BS2_{i,t-1} + \delta_3 SUM3_{i,t-1}$$

$$Model\ 4: \quad DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 SUM1_{i,t-1} + \delta_2 BS2_{i,t-1} + \delta_3 BS3_{i,t-1}$$

$$Model\ 5: \quad DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 BS1_{i,t-1} + \delta_2 SUM2_{i,t-1} + \delta_3 SUM3_{i,t-1}$$

$$Model\ 6: \quad DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 BS1_{i,t-1} + \delta_2 SUM2_{i,t-1} + \delta_3 BS3_{i,t-1}$$

$$Model\ 7: \quad DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 BS1_{i,t-1} + \delta_2 BS2_{i,t-1} + \delta_3 SUM3_{i,t-1}$$

$$Model\ 8: \quad DEF_{i,t} = \alpha_i + \beta GDP_{i,t} + \delta_1 BS1_{i,t-1} + \delta_2 BS2_{i,t-1} + \delta_3 BS3_{i,t-1}$$

Table 4 gives the estimation results of models 1 to 8 using fixed effects OLS with PCSE. Only the estimates of models 2, 4, 5 and 7 are all significant. The competing models are systematically evaluated against the seven others by running J tests. The results are given in tables 6 to 13 (see appendix). The last row of column labeled "test a_b" reports the coefficient of the J test. If this coefficient is significant, model b is better than model a. Table 5 summarizes these results. "Yes" means that the model in row significantly dominates the model in column while "No" means that model in row does not significantly dominate the model in column. As suggested by table 5, none of the seven other models are better than model 5 and model 5 always beats the other models except for model 4. According to these results, we may conclude that 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 (see Table 4). We now move on to a more detailed presentation and discussion of the evolution of NATO's strategy.

Table 4. *Estimation results of models 1 to 8 using fixed effects OLS with PCSE*

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
GDP	0.540***	0.527***	0.532***	0.516***	0.538***	0.506***	0.523***	0.507***
*SUM*1	-0.010	-0.011*	0.001	0.013**				
*SUM*2	-0.009	-0.013*			-0.013***	0.000		
*SUM*3	-0.013		-0.002		-0.017***		-0.013***	
*BS*1					-0.016***	-0.003	-0.012*	0.000
*BS*2			0.003	0.016**			-0.010*	0.003
*BS*3		0.010*		0.013*		-0.002		0.000
R^2	0.979	0.978	0.978	0.977	0.979	0.976	0.978	0.976

(*), (**), (***): respectively significant at 10%, 5% and 1% level.

Table 5. *Estimation results of the J tests*

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Model 1	.	Yes	No	Yes	No	Yes	Yes	No
Model 2	Yes	.	Yes	Yes	No	Yes	No	Yes
Model 3	No	Yes	.	Yes	No	Yes	Yes	Yes
Model 4	Yes	Yes	Yes	.	No	Yes	Yes	Yes
Model 5	Yes	Yes	Yes	No	.	Yes	Yes	Yes
Model 6	No	Yes	No	Yes	No	.	No	No
Model 7	Yes	No	Yes	Yes	No	Yes	.	Yes
Model 8	No	Yes	Yes	No	No	No	No	.

"Yes" means that model in row significantly dominates model in column.

4. Discussion and conclusion

In this study, we have used the now standard interpretation of NATO's strategies as the provision of joint defense products (Sandler and Hartley 2001). In the field of defense, multiple outputs whose publicness varies are involved, including local public goods (e.g., national interests' defense programs). Those ally-specific benefits are mainly derived from conventional forces and they yield no benefits to the other allies. However, conventional forces can also be deployed within the alliance, for instance in an effort to protect common exposed borders. Then, they are susceptible to force thinning. They can also be projected in joint peace-keeping operations, in which case a congestion effect may occur, when projection capabilities are overstretched by participation in too many such operations. Conventional forces when used in an alliance thus provide impurely public alliance-wide benefits.

Although NATO does use conventional forces, it is not a "conventional" alliance. After WWII, the Soviet Union is expanding westwards via satellite states. It also keeps running a heavy defense industry at a wartime pace. European democracies are rebuilding their economies while the United States largely converts defense industries to civil applications and markets. Western countries, which are not yet formal allies, thus face the expansionism of a Soviet Union which has acquired a conventional weapons advantage. The so-called Truman doctrine (after the declaration of March 1947) rests on the fact that the United States possesses the nuclear weapon whereas the Soviet Union does not. In this context, NATO is created in April 1949. Mutual assistance is formalized under Article 5 of the Treaty: "The Parties agree that an armed attack against one or more of them in Europe or North America shall be considered an attack against them all and consequently they agree that, if such an armed attack occurs, each of them, in exercise of the right of individual or collective self-defence recognised by Article 51 of the Charter of the United Nations, will assist the Party or Parties so attacked by taking forthwith, individually and in concert with the other Parties, such action as it deems necessary, including the use of armed force, to restore and maintain the security of the North Atlantic area."

The United States provides nuclear deterrence to its allies but its monopoly on nuclear weapons only lasts until August 1949! However, the nuclear effort of the western alliance is such that NATO soon has a first-strike advantage (through a pre-emptive strike aimed at neutralizing Soviet nuclear assets). Article 5 of the Treaty is complemented by the directives MC3 of October and November 1949 which explicitly mention nuclear strikes. Directive MC48 of November 1954 defines nuclear deterrence as a purely public alliance-wide benefit (Directives MC48/1 of November 1955 and MC48/2 of May 1957 describe more precisely the implementation patterns). NATO is thus an "unconventional" alliance set up in the emerging nuclear era. Doctrines and strategies will of course evolve afterwards, giving more or less weight to strategic and conventional weapons. Nevertheless, the joint product framework will remain and this "impurity of defense," as labeled by Sandler (1977) will adequately depict the strategic landscape of post WWII western security policy.

We have tried to contribute to another dimension of the debate on Nato, namely the way in which contributions of allies to their international organization articulate themselves in a "social composition function" to use the words of Hirshleifer. Broadly depicted, three such functions can be used when analyzing an alliance. A straightforward aggregation process is the summation of all the allies' efforts (for instance by adding troops or armored divisions to the joint forces). A quite different situation occurs when an alliance has to rely on the minimal contribution to ensure collective protection. In that case, aggregation follows a weakest-link technology. A third aggregator is the so-called best-shot, whereby the largest of the individual contributions determines the collective defense output.

Our intuition was that in the case of NATO, the summation and best-shot aggregators could be relevant but that we would have to find out the pertinent periodization. A single technology would not necessarily be relevant throughout our long period of study of NATO (1955-2006).

To investigate that, we have modeled allies' defense expenditures as a function of their GDP and of the aggregation technology.

It is always tempting to accumulate independent variables in the econometric regression in order to capture as many influences as possible. Though it cannot be contended that GDP summarizes them all, it may adequately synthesize the fiscal constraints faced by the allies over those decades of cooperation. As was expected, the contribution of an ally logically depends on the country's own GDP. We estimate that over the period 1955-2006, a 10% variation in country i's GDP would lead to a 5.38% variation of the same sign in its contribution to the alliance expenditures (see Model 5 of Table 4). Military budgets do depend on the ability of nations to produce wealth and they obviously are not disconnected from economic activity.

As to the core of our study, namely the nature and influence of the aggregation technology of contributions, we have allowed an unknown number of dates for technology shifts over the study period. Two breakpoints emerged, one in 1970, the other in 1990. These breakpoints thus delineate three periods characterized by different composition functions.

From 1955 to 1970, NATO's strategy relies mostly on the US military expenditures. More precisely, it rests on US nuclear deterrence as a credible commitment. We have previously mentioned that the United States has a first-strike advantage. It soon develops a second strike capability (its stockpile of nuclear weapons is sufficient to do so). In this context, we demonstrate that the best-shot technology of aggregation is predominant. Deterrence is mostly a pure public good. Since its benefits are largely non-excludable, one can expect opportunistic behavior on the part of the non best-shot allies. There would thus be a negative relationship between their defense outlays and those of the best-shot. Our estimates indeed show that a 10% increase in the US defense expenditures yields a 0.16% decrease in the defense expenditures of the other members of the alliance (see Model 5 of Table 4).

More surprising is perhaps the 1970 breakpoint since the institutional break is 1967. Our estimations illuminate the lag between the doctrinal decision and its actual implementation.

The doctrine of flexible response, or flexible escalation as it is sometimes and more adequately labeled, does receive political approval in May 1967 (DPC/D (67)23: Decisions of the Defence Planning Committee in Ministerial Session). This leads to directive MC14/3: its final version is issued in January 1968. Furthermore, this directive is complemented with a companion document, directive MC48/3 ("Measures to Implement the Strategic Concept for the Defence of the NATO Area"). As is made clear in its title, this directive aims at giving practical effect to directive MC14/3. Directive MC48/3 is issued in its final form in December 1969. It will shape NATO's strategy until the end of the Cold War.

From 1970 until 1990, NATO's strategy is that of the flexible response or escalation doctrine. It is adequate since the Soviet Union has intensified its production of nuclear weapons, thus lessening NATO's strategic advantage. Non-nuclear engagements are to be the first response to an aggression. Conventional forces should be used on the primary front or employed for the opening of a new ground front (or at sea). Afterwards, nuclear weapons can successively be used demonstratively, then selectively on interdiction targets. The general nuclear response is conceived as the ultimate deterrent only. In this renewed context, the complementarity between strategic and conventional forces is much bigger than during the previous period. This is really an era of joint defense products which requires and induces a greater involvement of the allies. Nuclear weapons can even have a quasi tactical employment on a conventional front, making them an element of the strategy rather than the strategy itself.

In this renewed context, one can expect that the technology of aggregation of contribution will move from best-shot to summation and this is what our results support. Strategic, tactical and conventional weapons are mixed and they become complementary in the overall strategy. The ensuing increased implication of allies should lessen opportunistic behaviors insofar as the share of non-excludable purely public benefits decreases. Since the participation of each member to the alliance now matters, free-riding could then be less pronounced than in the best-shot case, as indicated by Hirshleifer (1983). Our econometric results show that a 10%

increase in the defense expenditures of alliance members j≠i would lead to a 0.13% drop in the participation of country i to NATO's expenditures. NATO members still evince opportunistic behavior, however to a lesser extent than within a best-shot framework.

From 1991 until 2006, NATO's strategy dramatically changes as the international arena also dramatically moves to a post Cold War world. The new security challenges arise from nationalist or territorial disputes, resource claims, ethnic and religious conflicts. NATO's Heads of State and Government meet in July 1990 and they agree on the need to radically review their strategy. This leads to the Alliance's Strategic Concept of 1991. The next version of April 1999 confirms the initial one and provides inflexions with regard to the evolving international situation. The Comprehensive Political Guidance of November 2006 comes of course too late in our sample to have any effect.

The post Cold War security environment calls for a new strategy, usually labeled the crisis-management doctrine. NATO settles to the task of peacekeeping and peace enforcement. It contributes to regional or even world stability and security, which benefits both contributors and non-contributors. Beside this non excludable output, country-specific outputs take the form of post-conflict reconstruction and rebuilding contracts, assurances of more stability for countries in closer proximity to the conflict or with trade interests in the region. Nevertheless, there is plausibly a greater share of non excludable collective benefits associated with the alliance's new strategic concept.

Concurrently, the implementation of the new strategy rests on mobile forces drawn from multiple allies and deployed at great cost (from under $300 million in 1988 to over an annual $300 billion in the mid-1990s; Sandler and Hartley 1999). This increased tactical integration takes place in a context of dramatic declines in resources allocated to defense, due to the downsizing of forces. The collective outcome is thus subject to crowding effects. Rapid deployment forces are soon congested: the number of missions to cope with is such that the overstretching of capacities is a concrete threat. This is all the more so the case that the burden is mostly shouldered by the United States, France, Great Britain and Germany. Disproportion of efforts between the latter contributors and the others probably grows, amplified by the fact that projection capabilities require initial and sustained investment so that allies that do not invest in the first place cannot do it at short notice in case of a crisis.

On the whole, the summation technology remains the aggregator as confirmed by our estimations. Conventional forces are on the frontline, and the strategic nuclear forces stay behind. Sections 62 to 64 of the 1999 Alliance's Strategic Concept state it clearly. The nuclear forces of the United States, France and Great Britain keep to their mission of deterrence: they are there to "demonstrate that aggression of any kind is not a rational option" (Section 62).

The strategic context of the 1990s and after is such that there is probably an increased share of pure public inputs in NATO's activities. This is partly mitigated by the regional dimension of some conflicts (think of the Balkans) or of the economic stakes of others (think of Kuwait) which would dampen potential opportunism. One could thus expect increased opportunistic behaviors, but not necessarily a large augmentation. Our estimates for the last period of our study of the alliance show that a 10% increase in the defense expenditures of countries $j \neq i$ would yield a 0.17% decrease in country i's military expenditures. Compared with the 0.13% drop of the previous period, free riding increases (see Model 5 of Table).

To sum up, our panel data analysis of NATO over the period 1955-2006 evidences aggregation technology breakpoints in 1970 and 1990. We show that NATO follows a best-shot aggregator for 1955-1970 and summation for 1971-1990 as well as for 1991-2005. Free riding is always present. It decreases from the first to the second period as the share of pure public outputs of collective defense activities diminishes. Purely public benefits are more present during the third period, giving more room to opportunistic behaviors.

Embracing such a long time period and aiming to assess the huge endeavor of NATO obviously implies that our study has limits. We shall now try to point out a few of them. First, the evolution of the political context is not taken into account. Allies face internal pressures from their public opinions, their ideological inclinations vary through time and space. The fiscal constraint also evolves, with for instance a global increase in social security expenditures. As a further research step, one could envisage adding for instance dummy variables for left-wing or right-wing national policies, for countries with strong communist parties, etc. This would enrich the analysis, probably at the cost of less clarity with respect to our initial aim, which is more the assessment of aggregation technology change than behavioral analysis.

In a way, this last remark leads us to another limit of our analysis. We have not really clarified, if ever it is possible within our framework, why the alliance did switch from best-shot to summation composition functions. Was it more a matter of technology of conflict than of deliberate doctrinal choice? A partial answer lies in the consequences of the Cuban missile crisis. Initially set as a chicken game where the Soviet concedes but where the United States does not implement its threat of massive nuclear strike, the game is thus played cooperatively which helps avoid direct confrontation. The USSR then intensifies its production of strategic and tactical nuclear weapons, thus lessening NATO's strategic advantage represented by the US best-shot. The flexible response doctrine provides answers to acts of aggression that are commensurate to the actual threat. Conventional, tactical and strategic weapons become complementary. However, this remains to be further investigated, the two dimensions, technological and behavioral, remaining somewhat entangled in our study.

The previous interrogation brings in another one. If a shift in the composition function is identified, whether driven by technology or by deliberate choice, to what extent does it matter? Apart from the industrial and military consequences of the shift, we have shown that it has a significant impact on the opportunistic behaviors of the allies. In this respect, the aggregation technology matters. Once in place, the social composition of the alliance shapes the behavioral framework of the allies, for instance their choice between the supranational and the local defense public goods.

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Appendix

Table 6. J tests : Model 1 against the other models

	test1_1	test1_2	test1_3	test1_4	test1_5	test1_6	test1_7	test1_8
GDP	0.000	0.001	-0.018	0.072	-0.027	-0.274	-0.158	-0.098
SUM1	0.000	-0.018	-0.009	-0.010	0.025	-0.003	0.019	-0.008
SUM2	0.000	-0.018	-0.010	-0.010	0.025	-0.006	0.017	-0.010
SUM3	0.000	-0.019	-0.010	-0.012	0.025	-0.006	0.018	-0.011
J test coefficients	1.000***	1.019*	1.049	0.899**	1.042***	1.606	1.326**	1.258

(***), (**), (*) respectively significant at 1%, 5%, 10%

Table 7. J tests : Model 2 against the other models

	test2_1	test2_2	test2_3	test2_4	test2_5	test2_6	test2_7	test2_8
GDP	-0.239	0.000	-2.352**	0.049	0.035	-2.585**	-1.130	-2.067*
SUM1	0.009	0.000	0.0116*	0.011*	0.008	0.024***	-0.021	0.023***
SUM2	0.008	0.000	0.004	0.012**	0.008	0.010*	-0.028	0.012**
BS3	0.0107*	0.000	0.023***	0.011*	0.009	0.022***	-0.022	0.022***
J test coefficients	1.439	1.000***	5.413**	0.922**	0.927**	6.153***	3.216	5.111**

(***), (**), (*), respectively significant at 1%, 5%, 10%

Table 8. J tests : Model 3 against the other models

	test3_1	test3_2	test3_3	test3_4	test3_5	test3_6	test3_7	test3_8
GDP	-0.068	-0.630	0.000	-0.393	-0.216	-18.809	-0.438	-49.698***
SUM1	0.003	0.015**	0.000	-0.011*	-0.007	0.021	0.0125**	0.011*
SUM3	0.003	0.018**	0.000	-0.012**	-0.006	0.008	0.012*	-0.011**
BS2	0.003	0.015**	0.000	-0.014*	-0.008	-0.088	0.010**	-0.275***
J test coefficients	1.125	2.182***	1.000***	1.787***	1.406***	38.255	1.861***	99.024***

(***), (**), (*), respectively significant at 1%, 5%, 10%

Table 9. J tests : Model 4 against the other models

	test4_1	test4_2	test4_3	test4_4	test4_5	test4_6	test4_7	test4_8
GDP	-0.905	0.069	-3.803*	0.000	-0.585	-13.090	0.045	48.548
SUM1	0.017***	0.013**	0.006	0.000	-0.015	0.024***	0.012**	0.013**
BS2	0.015**	0.015**	-0.008	0.000	-0.018	-0.051	0.013**	0.293
BS3	0.023***	0.014**	0.024***	0.000	-0.013	0.015**	0.012*	0.035
J test coefficients	2.666**	0.865**	8.141**	1.000***	2.107	26.939*	0.935**	-94.698

(***), (**), (*), respectively significant at 1%, 5%, 10%

Table 10. J tests : Model 5 against the other models

	test5_1	test5_2	test5_3	test5_4	test5_5	test5_6	test5_7	test5_8
GDP	1.869	0.097	2.127*	1.135	0.000	2.444*	0.103	2.115*
SUM2	-0.010	-0.014**	-0.014**	-0.028	0.000	-0.011*	-0.012**	-0.012*
SUM3	-0.025	-0.015**	-0.031***	-0.035	0.000	-0.024***	-0.013*	-0.024*
BS1	-0.017***	-0.015***	-0.023***	-0.034	0.000	-0.025***	-0.013**	-0.024*
J test coefficients	-2.469	0.831	-2.982	-1.135	1.000***	-3.766	0.835	-3.105

(***), (**), (*), respectively significant at 1%, 5%, 10%

Table 11. J tests : Model 6 against the other models

	test6_1	test6_2	test6_3	test6_4	test6_5	test6_6	test6_7	test6_8
GDP	-3.144*	-0.572*	-4.862***	-0.355	-0.205	0.000	-0.422	0.085
SUM2	-0.020*	-0.016**	-0.004	0.011*	0.006	0.000	-0.012**	0.000
BS1	-0.011*	-0.015***	0.013*	0.013*	0.007	0.000	-0.010*	0.000
BS3	0.006	-0.013**	0.036***	0.013*	0.009	0.000	-0.010*	0.000
J test coefficients	6.842**	2.088***	10.121***	1.691***	1.378***	1.000***	1.845***	0.834

(***), (**), (*), respectively significant at 1%, 5%, 10%

Table 12. J tests : Model 7 against the other models

	test7_1	test7_2	test7_3	test7_4	test7_5	test7_6	test7_7	test7_8
GDP	4.064*	1.635	-7.868**	0.052	0.050	11.889	0.000	-4.156
SUM3	-0.041**	-0.041	0.011	-0.012**	-0.008	-0.021***	0.000	-0.013**
BS1	-0.024***	-0.037	-0.024***	-0.012*	-0.009	-0.027**	0.000	-0.011
BS2	-0.010*	-0.031	-0.052***	-0.012*	-0.008	0.041	0.000	-0.035
J test coefficients	-6.565*	-2.062	15.793**	0.929**	0.909**	-22.461	1.000***	9.232

(***), (**), (*), respectively significant at 1%, 5%, 10%

Table 13. J tests : Model 8 against the other models

	test8_1	test8_2	test8_3	test8_4	test8_5	test8_6	test8_7	test8_8
GDP	-0.408	0.062	-4.906***	-0.020	-0.089	0.024	-0.011	0.000
BS1	0.011	-0.013	-0.021	-0.020	0.005	0.003	0.006	0.000
BS2	0.011	-0.012	-0.039	-0.020	0.005	0.003	0.006	0.000
BS3	0.015	-0.012	0.001	-0.020	0.006	0.003	0.005	0.000
J test coefficients	1.709	0.869*	10.234***	1.058**	1.162***	0.955	1.026**	1.000***

(***), (**), (*), respectively significant at 1%, 5%, 10%

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