A Comparative Political Theory of National Science Provision

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Abstract- This paper examines the hypothesis that the national funding of science is a product of the process of governance. In support of this idea comparative theories of national governance are mustered. A mixed regression model is developed which examines the explanatory power of economic and political variables in determining science funding in an extended sample of OECD nations.

I. INTRODUCTION

The purpose of this paper is to test the hypothesis that national governance matters in science policy. Governmental actors are complex, multi-faceted, and above all constrained by institutional choices. Government policies for science are therefore likely to be far from ideal. Because of this science policy requires understanding of governance before advancing recommendations for policy. Governance variables present a natural basis for advancing "counterfactuals" about how the science system should be run, and how it might be advanced in absence of policy advocacy.

A. Two Theories of Policy

At stake are two different descriptions of governmental actors. The first is the government as an economically rational agent. The second is the government as a political entity with pluralistic and competing objectives. The economically rational account of science policy argues that there is a market failure in the provision of science. Science is a public good with considerable spill-over across institutional boundaries [1]. Since no single private entity can be certain to fully appropriate the benefits of scientific research, there will in general be an under-investment in science and technology. It is the role of the government to remedy this market failure, restoring the national science account by the selection and implementation of the correct policies. The nation then, in this theory of science policy, becomes a unitary actor with a "production function" of which science funding is a critical contributor to national productivity [2].

Contrast this account with positive political theories of government action. These theories describe the challenge of the government as one of capturing and allocating scarce resources in society. There are multiple interests, as well as political rivals who have an interest in capturing office [3,4,5]. The incentive of governmental officials is rewarding those shareholders who are central to the maintenance of government. Certain government styles may cause good policy to become good politics, but it is far from a foregone conclusion.

If this is the correct account of national science policy making, then the institutional features of the government have a substantial and perhaps even untoward effect in the distributional characteristics of science. Note that these are "positive" theories of government, meaning that although they characterize often undesirable behaviors on the part of government, these actions are explicable in light of a formal theory of actions, interests and incentives. This paper proceeds with a political hypothesis of national science policy action as we believe this perspective is under utilized and may offer additional and valuable insight.

B. Thesis Statement

This paper develops a regression model which attempts to explain national science policy preferences in light of internationally comparable measures of national governance. Significant relations between national governance and major indicators of science provision are revealed. These relationships persist even when other control variables of geography and economy are included. A substantial proportion of variance in national provision of science is explained. This proportion is significant enough to suggest that the policy preferences of governments are a lesser effect when compared with the procedural processes inherent in governance style.

II. THEORIES OF COMPARATIVE POLITICS

We find the work of two theorists of comparative politics particularly relevant to this research. Bueno de Mesquita (et al) [4] develops a formal and internationally comparable analysis of national government. The authors draw upon both democratic and autocratic theories of government to better understand the relationship between government policy and social welfare. Too often, Bueno de Mesquita argues, good politics results in ineffectual policy. The authors combine formal theory with empirical and historical analysis to defend this thesis. As a result they make a vigorous argument that democratic enfranchisement is the surest route to improved human welfare.

The purposes of Bueno de Mesquita and co-authors are somewhat different than our own. The authors have two policy levers available to a self-serving government: taxation, and the provision of public and private goods. The

government uses these levers to preserve power in a political system composed of rivals seeking to displace or even depose the government. The authors effectively characterize a broad range of national government types using two broad measures. The first measure is called the selectorate (S), or the proportion of the population empowered to select their leaders. This ranges from a diminishingly low proportion, to the universal adult suffrage seen in many Western nations. The second variable is called the winset (W), or the proportion of the selectorate whose approval must be secured to attain power. In some nations approval from only a small fraction of the selectorate is needed, as for instance is the case in military juntas or other oligarchic systems.

The second author of interest to this work is Arend Lijphart [3], who adopts an empirical and inductive perspective to comparative politics. Lijphart draws upon political theory to identify a broad range of variables believed to be of political import. These variables are then directly measured using archival analyses, and subjected to a factor analysis procedure to uncover two broad and underlying dimensions of governance. Lijphart focuses on Western democracies, as well as on a sampling of central American nations for his analysis.

Lijphart finds two broad factors suitable for describing common patterns of political governance across governments. The first factor distinguishes party-based systems from those with strong executives. Party-based systems are typical of parliamentary democracies, while strong executives are typical of presidencies and the so-called "Westminster" system. The second factor contrasts governments which are strongly centralized with decentralized or federal systems.

Lipjhart relates these revealed variables to economic performance as well as to social welfare and political stability. The economic performance of nations cannot usefully be predicted by either variable. There are, for instance, no meaningful differences between parliamentary and presidential systems in terms of long-term economic performance. Lijphart does however find that parliamentary systems do meaningfully outperform presidential systems in terms of social welfare and political stability. Despite Lijphart's caution in not generalizing his results beyond largely Western democracies, other researchers argue that his findings are evidence of governmental veto-processes at work which are widely applicable across governmental types [5]. Other authors have also attempted "actor-centered institutional" approaches to explain the economic policy preferences of nations [6].

Taken together, the works of Bueno de Mesquita and Lijphart provide a small set of variables which are useful to establishing broadly generalizable features of governance. These variables provide a significant insight into how the workings of governmental systems lead to desirable or less desirable choices of policy. However, to our knowledge, these comparative political theories have yet to be applied to science policy. In the following section we subject these theories to empirical analysis. First the data, which combines science policy and comparative political indicators, is described. A statistical method for the data is selected and justified. The third section describes the analysis; the fourth provides results and the significance of the model. The fifth and final section of the paper provides discussion and policy recommendations.

III. ANALYSIS

This section discusses the analysis method. The section begins with a discussion of the data, and follows with a rationale for the appropriate analysis. Then the analytical details of the selected method are presented. A confirmatory factor analysis, with associated significance tests of correlations, is the selected method.

A. Science System Data

The data set is selected to test the hypothesis, as formulated in the previous two sections, that political institutions matter in the governance of science policy. The cases used in the study are all OECD nations, plus an extended set of high technology nations including Russia and China. We use the latest available data as of 2009. The data used in this study includes three sets of variables: independent, conditional and dependent variables. We present each of these sets of variables in turn (see Tables I, II and III).

TABLE I
INDEPENDENT VARIABLES

Description	Source	Availability
Lijphart's executive vs parties dimension	Lijphart [3]	22 nations
Lijphart's federal versus unitary dimension	Lijphart	22 nations
Freedom House rating of political freedom	Freedom House [7]	All 38 nations
Selectorate Variable	Bueno de Mesquita et al. [4,8]	All 38 nations, however the sample includes only the high S nations
Winset Variable	Bueno de Mesquita et al.	All 38 nations, however variation in winset is imited
Scientific Winset	OECD, CIA [9,10]	37 nations; missing for Israel
Indicator variable for Constitutional or Monarchy	CIA	All 38 nations
Indicator variable for Federal	CIA	All 38 nations
Indicator variable for Parliamentary Democracy	CIA	All 38 nations
Indicator variable for Republican	CIA	All 38 nations

TABLE II
CONDITIONAL VARIABLES

Description	Source	Availability
Surface area	CIA	All 38 nations
Gross domestic product	CIA	All 38 nations
Population	CIA	All 38 nations
Indicator variable for U.S.A.	CIA	All 38 nations

TABLE III
DEPENDENT VARIABLES

Description	Source	Availability
Total expenditure	OECD	All 38 nations
Proportion of R&D financed by government	OECD	All 38 nations
Proportion of R&D financed by industry	OECD	All 38 nations
Proportion of R&D conducted by government	OECD	All 38 nations
Proportion of R&D conducted by military	OECD	All 38 nations
Proportion of R&D conducted by education	OECD	All 38 nations
Proportion of R&D conducted by industry	OECD	All 38 nations
Proportion of R&D conducted by military	OECD	10 nations
Nobel prizes	Nobel Foundation [11]]	All 38 nations

All data in the set are scaled appropriately for analysis. Proportional variables are transformed using the odds-ratio and the logarithm. Ratio variables are scaled using a logarithm.

B. Justification of Method

The data is appropriately modeled with confirmatory factor analysis. There are a few underlying dimensions which are assumed to explain both the inputs as well as the outputs. However these underlying dimensions are incompletely measured, and subject to multiple partial indicators. Partial political indicators include the multiple theories of comparative politics, which while largely congruent, are still challenged by direct verification in data. Indeed, part of the objectives of this analysis is to identify and make operational those significant variables of political study which are relevant for science policy. Partial outcome indicators include the multiple science provision indicators examined in this study. While the selected dimensions in this study are highly salient, they do not constitute the complete range of possible science provisioning variables which can be explained using these constructs.

An alternative paradigm for modeling this data would be the regression analytic technique. A regression approach is partially adopted by including a number of economic intermediary variables. However a full regression analysis of output based on both politics and economics is not attempted in this study. As a result we must be cautious about drawing conclusions about the statistical conclusions from this study, since a mutually satisfactory fit of both input as well as output is attempted using factor analysis. Significance of correlations are offered as a diagnostic; the sufficiency of these correlations must depend on the adequacy of the theory underlying the observed correlations.

C. Technical Description of Method

Consider the following interlinked set of variables. Capital letters are vectors, lower case Greek letters are scalars, and script letters are random variables. Subscripts on each of the vectors are suspended for brevity. The variable W represents the governance variables. The variable X represents the economic proxies. The variable Y represents the science provision variables, and Z represents the full set of political indicators (equations 1).

There are two sources of Gaussian noise, N_1 and N_2. Link functions are used where appropriate for discrete dependent variables. The governance variables are unobserved in the data, but estimated from the model. Further, the parameters (α, β, γ) are estimated using the model.

$$Y = \alpha X + \beta W + \mathcal{N}_1$$
$$Z = \gamma W + \mathcal{N}_2$$
(1)

The model contains some aspects of factor analysis as well as of regression analysis. The model is using maximum likelihood estimation; missing data are replaced using an expectation maximization procedure. Note that the model is highly parsimonious since only a few hidden governance variables are used to explain both the full set of political and science provision variables. In this case two governance variables are estimated.

A model is fit which estimates two hidden variables, hypothesized to be related to policy variables. These policy variables serve as best fitting descriptors of a range of associated indicators of national governance. Furthermore these policy variables serve as best fitting predictors of science policy provision, conditioned on traditional economic variables such as land, labor and capital. Alternative models are evaluated using informativeness criteria. These results are not reported here for space, but the model appears robust and unlikely to be overfitting the data.

IV. RESULTS

In this final results section four archetypes of national science provision are presented based on the model results (see Table IV). No single nation corresponds in the ideal to these types; the results are abstracted based on results from multiple nations. The model abstracts away economic, population and geographic-level detail to focus on a hypothetical average-sized country from each of the four policy styles.

The commensal style of science provision is seemingly run by industry and on behalf of industry. Total science funding is highest in this system, and participation in the

scientific workforce is also the highest. Belgium is an exemplar of this style. The federal system, as exemplified by France, has a mix of government and industry funding, with strong participation by both the industrial system and the academic sector. Conditioned on population and economics, nations under a federal system are expected to receive the majority of the world's Nobel prizes. The majoritarian system is run on behalf a strong executive branch, pursuing military or other programmatic objectives. There are strong national R&D laboratories, but total R&D funding has dramatically diminished compared to the other styles. The Polish system exemplifies this style. The unitary style is strongly centralized in pursuit of governmental objectives. It incorporates some of the stronger aspects of the commensual style with strong R&D funding and participation by the governmental sector.

TABLE IV
FOUR ARCHETYPES OF SCIENCE PROVISION

		Commensual	Federal	Majoritarian	Unitary
Representative Nation		Belgium	France	Poland	S Korea
Loading	Dimension 1	1	1	-1	-1
	Dimension 2	1	-1	-1	1
Expenditure		27,280	7,740	1,710	6,027
Funding	Industrial	83%	44%	27%	70%
	Governmental	17%	56%	74%	30%
Participation	Industry	78%	40%	24%	66%
	Education	9%	34%	34%	11%
	Government	4%	3%	15%	14%
	Military	1%	7%	10%	2%
Outcomes	Nobel Prizes	12%	76%	11%	1%

VI. VALIDATION

A. Significance Testing

In this table the results are subjected to significance testing. The correlations between the policy dimensions and the independent variables are tested (see Table V), and Pearson's r test of significance is applied. A similar test is then applied to the dependent variables (see Table VI).

The main political indicators are correlated with one or more of the policy dimensions with a significance exceeding $p=0.01$. The policy dimensions also adequately describe two of the four political descriptive labels included in the CIA Factbook. A more appropriate parametric test for these categorical variables would involve significance tests for a logistic model. These tests are not given here as the most salient features are reproduced with the Pearson's test.

TABLE V
CORRELATIONS WITH INDEPENDENT VARIABLES

	Dim 1	Dim 2
Dim 1	1.00	0.00
Dim 2	0.00	1.00
F1	0.33 *	0.68 **
F2	0.51 **	-0.57 **
Freedom	0.45 **	0.17
W	0.77 **	0.20
Sci Win	0.72 **	0.36 **
Constitutional Monarchy	0.44 **	0.10
Republic	-0.12	0.04
Parliamentary Democracy	-0.06	0.08
Federation	0.38**	-0.20

*   Variable is significant at $p < 0.05$
**   Variable is significant at $p < 0.01$

TABLE VI
CORRELATIONS WITH DEPENDENT VARIABLES

	Dim 1	Dim 2
dim 1	1.00	
dim 2	0.00	1.00
expend	0.41 **	-0.58 **
ind_f	0.46 **	0.42 **
govt_f	-0.56 **	-0.40 **
ind_p	0.56 **	0.36 **
edu_p	-0.15	-0.27 *
govt_p	-0.63 **	-0.25
mil_p	-0.04	0.32 *
nobel	0.67 **	-0.65 **

*   Variable is significant at $p < 0.05$
**   Variable is significant at $p < 0.01$

The main science policy provision indicators are correlated with one or more of the policy dimensions with a significance exceeding $p=0.05$. Educational participation in national R&D, and military participation in R&D are at a lesser degree of significance. These results strongly endorse the role of dimension two (a measure of policy centralization) in creating desirable science provisioning outcomes. Note that it is decentralized governance (a negative loading on this variable) which is associated with favorable policy outcomes.

The situation is more ambiguous with dimension one, a measure of executive versus party dominance in science policy governance. Although there are significant relationships between this variable and most of the science policy provisioning outcomes, it is not clear from these results that there is unambiguously a better style of governance. Strong executives have good national laboratories, significant military R&D, and strong participation by academia. Strong parties have significant funding, good industrial participation, and as seen by the scientific winset have large science and technology workforces.

B. Comparing Economic and Political Explanations

In this section we return to the two theories of policy presented in the introduction. Five different regression models including various combinations of explanatory variables are presented in an effort to distinguish the effects of economics from politics in science policy provision (see Table VII). Only one of several possible dependent variables is presented -- total R&D expenditures. The other regression equations are omitted for brevity, as they show similar outcomes.

The first thing to note about these equations is the high quality of explanation which is provided. A second thing to note about these models is the fact that the economic explanations explain a greater proportion of the variance than the political or policy explanations. Obscuring the relationship is the fact that high population countries in general require a higher degree of policy decentralization. Thus the economic variables incorporate some of the joint geopolitical explanations from which both politics and economics are derived. As evidence of this the influence of dimension 2 (policy decentralization) switches signs once population is included in the model.

TABLE VII
PREDICTING NATIONAL R&D EXPENDITURES

	Model 1	Model 2	Model 3	Model 4	Model 5
	Econ Variables	Econ Variables with U.S. Outlier	Policy Variables	Policy Variables with US Outlier	All Variables
Intercept	-0.37	0.83	8.86 **	8.84 **	-10.88 **
Dim 1			0.53 **	0.50 **	0.76 **
Dim 2			-0.75 **	-0.71**	0.63 **
population	0.52 **	0.46 **			1.14 **
GDP	0.15 **	0.16 **			-0.00
land	-0.06	-0.09			0.06
USDummy		2.42 **		0.78 *	1.00 *
R-Squared	83.6% **	86.8% **	71.2% **	71.6% **	98.5% **

*   Variable is significant at $p < 0.05$
**   Variable is significant at $p < 0.01$

A few final comments on the models are provided. First is that there is a U.S. exceptionalism effect, as evidenced by the regression dummy. The United States funds nearly three times the research and development one would expect given its size. The effect is somewhat diminished once the political variables are incorporated in the model, reflecting the strong decentralization of government in the U.S. A further note is the surprising absence of GDP as a determinant of R&D funding. GDP is perhaps the most common benchmark for assessing R&D funding adequacy and yet, in this developed and developing world sample, it shows no statistical relationship with science provisioning.

VI. RECOMMENDATIONS AND CONCLUSIONS

The concluding section of the paper offers recommendations for future research as well as for science policy. The section begins with discussion and commentary on the results. The section focuses on needed new results both empirical and conceptual.

A. Recommendations

In this section the paper turns to recommendations for science policy. In particular the section considers the consequences of differing governance mechanisms resulting in significant differences in national governance of science. Given these conclusions, policy recommendations for national funding must be more nuanced than spending a fixed proportion of national GDP. In particular, for many nations a systematic change in science governance may be needed. In the first section we try to identify those nations with beneficial governance systems. In the second we consider specific characteristics of the national systems of innovation associated with these countries. Third and finally we consider how nations should seek peers if GDP is not an effective measure.

The data and model presented concerns inputs to the science system. Therefore, we must be cautious in declaring that some governance systems provide univerally better outcomes than others. Despite this caution, it does appear that most of the desirable inputs to science policy are achieved more readily by federal systems of governance. We therefore turn in the following sections to find the most federal systems in the sample, and to discover whether their science policy outcomes appear more or less federated than their governance would otherwise suggest.

B. Governance Mechanisms

Figure 1 below contrasts Lijphart's federalism variable (F2), as directly and empirically measured with the federalism results as estimated by this study. Discrepancies between the two may be a measure of noise, or they may reveal nations which have systematically attempted to shield their science base from an overly centralized system of governance. The F2 variable, both actual and estimated, is plotted in figure 1. (Only those nations with a Lijphart score prior to modeling are included in the plot.)

The U.S., Canada and Germany are highly decentralized, but have apparently not achieved the full and expected benefits of this federalization in their science system. Switzerland in particular appears to be scientifically more centralized than its national system would imply. France and the United Kingdom are moderately centralized countries according to Lijphart, but are nonetheless achieving significant benefits in their science system despite this degree of centralization. New Zealand appears much more decentralized than described by Lijphart, but is still far too centralized to fully capitalize on these benefits in the science system
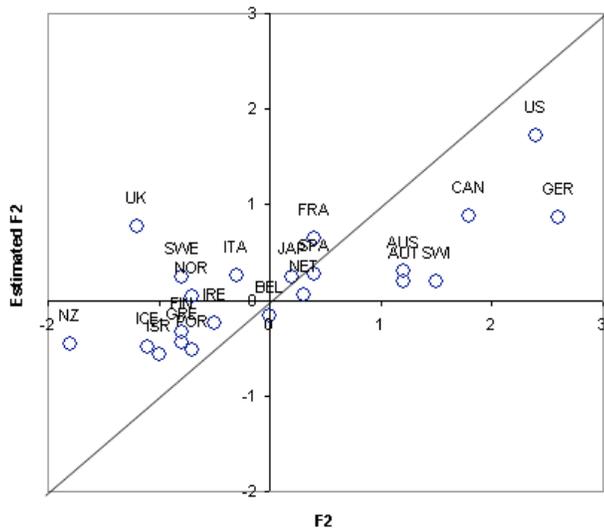
Fig.1. Estimates of Federalism

The results of the previous section suggest that we more closely examine the science systems of the United States, Canada, and Germany, in order to better characterize these three decentralized systems of innovation. New Zealand and the United Kingdom stand out as nations which may have effectively shielded their science base from an otherwise highly centralized governmental apparatus. In particular, we are looking for institutional design variables used in these countries which shield science funding from the negative effects of centralized governance. Unfortunately this effort must be reserved for future work. This work is likely to build on results from national innovation systems (c.f. [12]).

B. Conclusions

In this paper formal models of politics and governance are used to explain science provisioning outcomes in an expanded selection of OECD nations. Governance variables are introduced into an extended linear model using both regression and factor analytic elements. The paper finds a very significant role of political and governance variables in explaining science policy outcomes. Contributions are made in identifying high performing institutional designs for science policy. Additional contributions are made in recognizing appropriate metrics for the comparative benchmarking of nations in terms of science provision.

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