The Economics of Scientific Research Coalitions: Collaborative Network Formation in the Presence of Multiple Funding Agencies*

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*Stanford University and All Souls College, Oxford; and University of Wisconsin and CEP, LSE. Corresponding Author: Economics Department, 1180 Observatory Drive, Madison WI 53706 USA; lkeely@ssc.wisc.edu. Presentation of the first draft of this paper at the NPRnet Workshop held in Paris on 5-6th May, 2000, provided a numerous comments and suggestions that were useful for improving and tightening the exposition. We wish to express our gratitude to the assembled members of the NPRnet Project and the invited discussants, particularly the papers designated discussants – Bronwyn Hall and Cristiano Antonelli. Further comments were received, from Jonathan Cave and others at the Warwick Summer Research Institute, where a subsequent draft of the paper was presented on 14 July, 2001 to the session on Modelling Networks and Network Games. The present version has benefited from the comments of an anonymous reviewer, and the liberality of the editors of this volume. Davids research in connection with this paper drew support under the NPRnet Project sponsored by the STRATA Programme of the Directorate General of the European Economic Commission, and coordinated by SPRU at the University of Sussex.

1. Introductory Overview: Motivation, Approach and Results

A global trend towards the formal collaborative organization and conduct of scientific and technological investigations has been promoted by the increasing scale, "lumpiness," and complexity of research and development opportunities[1]. Understandably enough, there has been a corresponding increase in the attention and effort devoted by economists to describing the various phenomena associated with the proliferation of cooperative R&D agreements among firms, multi-institutional research partnerships, and international scientific consortia; as well as to accounting for the characteristics of the entities (whether business firms, university schools and departments, or public institutes) that exhibit strong propensities to enter into coalitional arrangements of this kind[2]. This is very much in order, inasmuch as the increasing ubiquity of collaborative modes of research that transcend national boundaries calls for some critical rethinking of traditional national science and technology policies, an undertaking for which there is none too ample a supporting basis of empirical findings and analytical constructs[3].

The growing recognition of the collaborative context within which individual researchers typically function, and the respects in which their organizational arrangements do not conform to the ideal of a "perfect team" organization within which the incentives of the constituent agents have been so aligned that the collectivity can be viewed as a monolithic entity, are new and welcome departures from past research approaches in the economics and the sociology of science. Strong traditions in economics analysis favored accepting the individual researcher, rather than researchers and their colleagues, situated in laboratories, as the relevant unit of analysis. This predisposition was reinforced by the impetus that early studies in the economics of science received from concerns with "scientific manpower" policy issues; the latter were approached simply as a matter of applying the economic

[1] Although the emergence of research collaboration in "Big Science" fields was viewed from the 1960s onwards as a significant novelty reflecting underlying tendencies in the organizational structure of modern science, the increasing generality of collaborative organization is now attracting fresh interest as the most recent phase in a broader, longer and more continuous development. See, e.g., Katz [22], Katz and Martin [23], Etzkowitz and Kemelgor [12].

[2] See, e.g., Coombs et al. [5], Mowery, Oxley and Silverman [30], and Mowery [29]. For recent studies examining these developments in the western European context, with references to the corresponding literature focused upon US experience, see Gambardella and Malerba [16].

[3] The task is briefly essayed by Hicks and Katz [21].

analysis of individual labor supply decisions[4].

In the more normatively oriented discipline of research management, analysis has been geared to finding the best means of motivating, coordinating and directing the activities of closed teams (comprising employed scientists and engineers) dedicated to achieving specified tasks that serve the externally stipulated goals of a supporting organization, such as a commercial corporation or a public mission agency. The organization and behavior of more autonomous groups of academic researchers who involved themselves in research coalitions hardly fits neatly into either of these approaches.

1.1. Motivating Considerations

Although one might have expected the study of collaborative research to have been a staple in the field of organizational sociology from the latter's inception, such was not the case. On the contrary, the sociology of science, having initially been preoccupied with macro-institutional analyses following the line of inquiry opened by Merton [28], only belatedly came to concern itself with the microcosm of scientific work groups comprising researchers situated in specific laboratories. But, rather than attaching special significance to formal structures of collaboration, the thrust of more recent developments in the sociology of scientific knowledge has somewhat paradoxically directed primary attention to situating the individual actors and their apparatus and artifacts within larger relational networks, and to "following scientists and engineers through society" without particular reference to the nature of the organizational structures within which their activities were conducted[5].

For these and still other reasons, comparatively little systematic attention has been given the impacts upon the relevant research communities of the recognized trend favoring provision of public funding to scientific and technological research projects that are conducted in formal "collaborative networks," especially those that assemble research units from a variety of academic institutions and business entities under various forms of contractual agreement[6]. Indeed, the study of re-

[4] See the discussion in Stephan [35], whose early contributions exemplified the focus of economists upon individuals; and also, Stephan and Levin [36].

[5] See, e.g., Latour and Woolgar [26], Latour [25], Callon and Rip [4], Callon [3].

[6] This is to say that enough of a beginning has been made (e.g., in Gambardella and Malerba [16]: chs. 13-15) to suggest both the interest and promise that the subject of publicly funded formal research collaboration holds, and to indicate the enormous amount of work that has yet to be done. In what follows here, it should be understood that the focus is upon formalized

search collaborations predominantly or exclusively formed among public sector research entities in the physical, engineering, medical, social and behavioral sciences, remains essentially in its infancy. This is so both in an absolute sense, and in relation to the growing mass of empirical material pertaining to inter-firm R&D agreements, and government sponsored research "partnerships" involving university- and industry-based research units.

To guide the decisions about resource allocation in all these related areas, obviously, one would hope to draw upon more ample and firmer knowledge than we now possess about the ways in which the terms of such programs affect the structure and performance of the R&D coalitions that are successfully formed. What is the effect of special programs targeting the collaborative conduct of scientific research upon the distribution of research competence, scientific reputational standing, and access to resources within the research communities at large? When there are some sources of funding that stipulate particular forms of collaboration as a condition of eligibility to compete for support, how does their influence interact with that of other research agencies that continue to provide research support without imposing organizational conditions favoring the formation of "collaborative networks"?

The latter query raises a more general problem: non-profit (charitable) foundations, public agencies and government departments which concurrently engage in sponsoring research activities may rarely do so in a tightly coordinated fashion even when all their funding is concentrated within a single national domain. A multiplicity of differentiated goals among the sources of funding, some quite idiosyncratic, some quite mimetic and rivalrous, presents both opportunities and potential conflicts that influence the growth, structure and performance of research communities. Diversity of funding agencies operating in a given field of scientific exploration and application often is a correlate of the sheer extent of the aggregate resources that can be mobilized for research. But, insofar as diversity, and the degree of coordination or decentralization among the programs run by the different funding sources represent a subject of policy design, we should ask what differences it makes to the effectiveness of any particular agency's strategy

collaborations ("coalitions"), as distinguished from informal cooperative actions by individual researchers (whether or not productive of co-authorship, or co-patenting) that may be viewed as particular instantiations of the "communal ethos of science" discerned by Merton ([28]: p. 273): "The substantive findings of science are a product of social collaboration and are assigned [in the sense of ownership] to the community." For analyses of the relationship between the Mertonian norms and the micro-level organization and collective performance of epistemic communities as "invisible colleges," see Dasgupta and David [6], David [9].

that its programs are not "the only (funding) game in town."

Quite patently, it is seriously misleading for science and technology policy-minded economists to go on pre-supposing that they should devote themselves solely to working out the best advice to give in this sphere to a governmental funding authority that is able to allocate all the relevant resources available to the research groups operating within its domain. Some public agency directorates do resemble the classic corporate executive board that has exclusive responsibility for the company's R&D projects, and corresponding control over all of its research resources; and in some of the smaller developing economies, there are unitary, centralized government research boards. But, such a degree of centralization in research funding, where it obtains, is likely to exact a price in terms of the loss of diversity and breadth of vision about matters that are inherently hard to predict. Consequently, even where it is possible to impose a unified structure of coordination and control, it well might not be thought desirable to do so.

What is wanted, therefore, is a mode of policy analysis that takes explicit account of the existence of a multiplicity of R&D funding bodies that are operating in essentially the same areas of scientific inquiry but may be pursuing distinct goals that will be reflected in differentiated criteria for project selection.

1.2. Focal Problems for Economic Analysis

In the present paper we cannot hope to satisfactorily address the entire nexus of issues that are spotlighted by the foregoing questions. Rather, it has the considerably more modest goal of making some headway towards a clearer identification and understanding of the resource allocation problems posed by the two empirical features of the world. Curiously, although these conditions commonly are ignored by theoretical analyses that propose economic rationales for public programs of research support, it is now ubiquitously apparent that close collaborations may exist among research units, but not necessarily among their potential sponsoring institutions.

The first aspect of reality that we thus must notice explicitly is that, typically, there will be more than one public funding agency whose policies and programs need to be considered. Within a given national domain there are numerous government agencies, each of which has its own mission and particular goals. It has been noted that competition among rival agencies for the services of experts, including those who are expert in the production of reliable knowledge, in general has the effect of allowing the expert agents to extract better terms of support from their patrons and principals[7].

While this may well have a direct and important bearing upon the terms and the volume of funding provided for scientific and technological research in the aggregate, that aspect of the influence exerted by the degree of coordination prevailing among sponsoring agencies is not the primary focus of concern here. Instead, we concentrate on the equally interesting, but less studied question of what happens when there are different funding agencies which have quite different objectives, and so might adopt rather different funding criteria. Focusing on such situations deliberately is intended to exclude the entire class of problems that are usually modeled in the economics of R&D, namely the choice of strategies made by funding organizations whose conflicting goals differ in a symmetrical manner. Such is the case in a so-called "patent race," where rival research sponsors in effect seek to attain the same scientific or engineering objective, but each has the goal of achieving it before all the others.

The second aspect of the observable research scene is that the research units self-organize themselves into coalitions seeking support for proposed projects. Except in the case of public agency procurement contracting, with which we are not concerned here, the sponsoring entity is thus presented with a set of pre-bundled capabilities. Rather than being in a position to assemble the teams that it would wish to fund in a collaborative project, the public agencies responsible for such programs typically must select among the coalitions that have been constructed with a view to gaining their support. Consequently, in each round of funding an agency's choice set reflects the outcome of the constituent units' efforts to place themselves in as attractive a company as is feasible.

Those efforts, in turn, are predicated upon the research units' knowledge of their own capabilities and those of their peers. They also reflect what is believed about the respects in which appraisal made by their disciplinary peers may diverge from the opinions that are held within the funding body as to the (reputed) abilities and attainments of the pertinent candidates for coalition partnership. Equally influential in the efforts to form coalitions that will prove successful in the competition for support are the researchers' beliefs about the goals of the collaborative research program and the selection criteria that have been set by the administering agency.

It is no less important to recognize that the research coalitions in question are quite malleable, and in general impose commitments of only rather limited

[7] On the effects of "common-agency contracting" involving multiple sponsors and research agents, see David [8], David [10].

duration upon the members, even when the latter are bound together by formal agreements. The structure of these coalitions may well reflect underlying social relationships among some of the individuals belonging to the constitutive research teams, and the experience they have gained in collaborating successfully on previous projects may induce recurring clusters of participation in successive undertakings[8]. Scientific research collaborations of this variety thus fall neatly into the organizational category of "networks," being a form more enduring and socially grounded than the canonical anonymous spot-market contract, but more readily formed and dissolved than the canonical business firm.

Their comparative plasticity, or malleability, carries the implication that their composition is more likely to be endogenously determined. The collective characteristics and attributes of the network organizations that compete for funding, therefore, are not fixed by those of the aggregate ensemble of human research agents, nor by its individual members, if only because the latter are able to assemble and re-assemble in different configurations designed to meet their prevailing perceptions of the properties of the feasible arrangements that will prove most attractive to the sponsoring agency. Research capability, in particular the ability to successfully carry through the project that the network proposes, naturally is likely to be prominent among those properties. But, except where very specific and restrictive research objectives are stipulated (as in procurement contracts), the scientific and technical goals may be adjusted to accommodate the strengths and limitations of a collaboration which has formed with a view to providing other "qualities" that are thought to be even more attractive to the funding agency.

In view of the significance that academic research communities attach to researchers' reputational standing derived from collegiate peer assessments, not only as a measure of prestige but as a basis for a variety of professional rewards that include access to research resources, it is reasonable to regard considerations of scientific reputation as occupying a central role in the self-organization of research coalitions. Empirical studies of the allocation of public funding and its impact upon the productivity of research units points to the importance of distinguishing between the effects of research competence and scientific standing or reputation. Competence can build reputation by affecting the record of past experience and

[8] Garcia-Fontes and Geuna [17] present systematic statistical evidence of such patterns of repetitive participation on the part of European university-based research units, notably those drawn from the stronger institutions, who received funding under successive EU Framework Programs. Evidence from casual empirical observation is more abundant and points in the same direction.

achievement, but in the natural sciences and engineering it is necessary to secure significant material resources in order for the abilities of an individual or a group to express themselves in observable accomplishments.

Moreover, the receipt of public funding itself carries a signal that generally augments and rarely if ever diminishes the recipient's scientific repute, even where considerable uncertainty surrounds the exact nature of the evaluation criteria upon which the award of support had been based. Reputation thus figures as a basis of perceived competence, not simply because hearsay may readily be substituted for knowledge of the true state of a research unit's capabilities; but because there is a dynamic relationship through which "reputation" affects the likelihood of securing access to the wherewithal for demonstrating those capabilities. Inasmuch as "reputation" is a property that by definition is readily knowable, and generally will be widely known within the relevant epistemic community, it is quite understandable that this attribute of a research unit should tend to figure more powerfully in the competition for research support.

Reputational standing within scientific peer groups thereby occupies the critical role in the formation of a positive feedback mechanism – described as "cumulative advantage" and famously labeled "the Matthew Effect" by the sociologist of science, Robert Merton [27]. That type of dynamic process, which has been found to operate at the level of research units as well as that of the individual researcher, tends to generate stratification in the distribution of research productivity and reputational standings. Competence, by contrast, is a less certain quality. It often has many more dimensions, but nonetheless remains difficult to assess ex ante by reference to quantitative indicators. Such "objective" measures of research competence, not surprisingly, are found by empirical studies to have a less predictable bearing upon the scientific productivity of those units that proved successful in mobilizing equivalent levels of material support[9].

1.3. Theoretical Approach, and the Principal Findings

The motivation for this paper therefore derives from the conviction that a useful analytical check can be provided for the intuitive explanations that may be offered for the observed patterns in the organization and conduct of collaborative R&D under the aegis of the EC. But, to do so requires developing a more appropriate

[9] For the original formulation of "the Matthew Effect" see Merton [27]. On the roles of reputation and competence in scientific research productivity see, e.g., David [7], and Arora, David and Gambardella [1].

theoretical framework than those available hitherto. More specifically, what is needed is a formal model of coalition-building ("network" formation) among research units that seek competitive funding from a supra-regional program, while also drawing support from their respective regional funding agencies. Further, such an analytical structure should admit the possibility that the different governmental entities engaged in supporting research may each follow a distinctive strategy with regard to the project selection criteria they employ. This approach enables one to ask whether there are stable (equilibrium) outcomes in the interactions among the several funding entities, and to investigate what those outcomes would employ for the evolving distribution of scientific performance within the entire region and its national sub-regions. From the latter, as will be seen, some insights emerge regarding the nature of the optimal strategies that may be pursued by the various funding agencies in such a system.

The analysis of the paper proceeds in two steps. First, a model is developed to analyze how collaborations are formed under different sets of funding rules of an international funding institution. In this first model, there will initially exist a finite number of research units with an associated distribution of reputed quality, or reputation. The research units may form collaborations in expectation of receiving external funding for their collaboration's research. Collaborations will form in each period according to a set of procedures, described in detail below. Once collaborations are formed, then each of the proposed networks (coalitions) may be awarded some external funding in that period, but not every one of them will be successful in attracting support. The level of funding received is determined according to a rule comparing the distribution of reputations within and across collaborations. Several possible external funding rules are analyzed to determine how they impact upon collaboration formation. The evolution of the reputation distribution is tracked with these collaborations.

The first model analyzed in this paper is a repeated non-cooperative game of coalition (or collaboration) formation with the distribution of payoffs within the collaboration according to a fixed rule. Non-cooperative games of coalition formation developed by several authors, including Bloch [2], and Ray and Vohra [31], provides a useful framework for this work. Keely [24] applies this type of game to a multi-period setting in which a distribution of coalitions is tracked.

The results of this model under various rules are compared with empirical evidence on EC research collaborations to determine which rules are consistent with the evidence. In the second step, various combinations of national and supranational funding regimes are examined, but all the rules considered stipulate that collaborations are funded as a whole, regardless of the number of members; and that their funding is determined by the absolute level of average reputation, or of the variance in reputation, rather than just the rankings of the proposed networks. To characterize the outcomes, we examine these two moments of the endogenously determined distributions research "competence" (signalled by the reputation measures) the entire ensemble of research units and its national partitions).

The main conclusions of this simple model of collaboration formation can be summarized in the following way. If the funding institution chooses to fund collaborations of the highest variance in reputation (to promote convergence) rather than collaborations of the highest average reputation (to promote excellence), then leapfrogging in the distribution of reputation by research units becomes possible. Persistence in the collaboration patterns occurs when the funding institution chooses to fund collaboration of the highest mean reputation. Coalitions of a size greater than two are possible only if collaborations are funded on a per unit basis within the network, rather than fixing the level of funding on a per network basis.

The second step of the analysis considers a model with both a supra-national funding agency (such as the EC), and national funding institutions and agencies. For simplicity we abstract from the multiplicity of funding bodies operating at and below the national level, and consider each of the national domains as an integral funding regime. Within each nation there exists a population of research units and an associated distribution of "scientific reputations" based on current perceptions regarding the units' respective "competence." The latter is assumed to be described completely by a cardinal scalar measure. Each of the agencies has a funding rule that can be varied parametrically, and these rules interact to produce a national and supra-national effect on the average and variance of the research reputation of research units within and across nations. Underlying each rule chosen is a supposed goal that the funding entity seeks to attain. It is possible for different sets of rules to work toward or against the goals of the other funding agencies. For example, a funding rule by the supra-national agency may have an effect on the distribution of research competence in the region that is offset by the funding rules chosen by national agencies.

An example is examined, based upon a particular specification of the model in which both multiple national agencies and a supra-national entity provide funding for collaborations within the supra-national domain. This makes it possible to evaluate the consequences of different sets of funding rules, and thus to identify the best response of each agency to the other agencies' funding rules. A Nash equilibrium of funding rules is thus identified for each set of possible national and supra-national agencies' policy goals. Again, the absolute means and variances of the resulting reputation distributions for the ensemble of research units, and for its national partitions, are examined; the corresponding rel-variance measures also are considered.

It is found that when all the funding bodies seek to maximize the average reputation, or to minimize the reputation variance of research units in their respective constituencies, then the best possible outcome for each entity coincides with the Nash equilibrium. The same results obtain when all the funding agencies seek to minimize the respective regions' variance relative to their regional mean levels. Further, it is seen that national agency strategies should involve funding choices that are independent of supra-national funding choices. the outcomes obtained when such (independent) national strategies are followed always dominate those obtained where national funding allocations are conditioned – whether as supplements or offsets – on the allocations made by the supra-national agency. This analysis suggests that further research should focus not on the potential conflict between the EC's own objectives, but, instead, on the policies that national governments have adopted in view of the presence of EC programs that support research collaborations.

1.4. Organization of the Paper

Section 2 describes a concrete context in which the set of generic R&D policy issues identified by the foregoing discussion are manifestly present: the territory that the Research Directorate of the European Commission recently has begun to refer to as the "European Research Area (ERA)." The model of research coalition (or collaborative network) formation presented in Section 3 is, in a sense, a caricature of the process through which R&D proposals involving multiple research units are developed. The outcomes of the funding of some among the proposed coalitions over several periods are analyzed under the different external agency funding rules and initial reputation distributions, for the case in which individual research units all are sustained by equal fixed levels of internal funding. Particular attention is given to the size, persistence, and relative reputational standings of the endogenously formed networks (coalitions). In Section 4, some empirical evidence is reviewed regarding European research collaborations that have been funded under the EU Framework Programmes. These observations are compared with the analytical results obtained with the simple model of Section 3, and they are used to obtain the model presented in Section 5. In the latter various rules for the funding for trans-national research networks under a supra-national agency, are combined with alternative funding policies adopted by national entities for supporting individual research units within their respective national domains. The Nash equilibria corresponding to the various possible policy regimes are examined; a numerical simulation example is presented and the implications and robustness of the results are discussed. Section 6 concludes the paper, reporting some preliminary results of efforts to ascertain the robustness of the main findings through simulation studies of variant specifications.

2. A Concrete Policy Context: The European Research Area

Certainly one of the notable features of the institutional arrangements for the public funding of scientific and technological research in the European Union (EU) is the co-existence of a multiplicity of funding programs that are organized and financed by different levels of government. Such a situation in itself is by no means unique, as it emerges quite naturally within federal governmental structures. Thus, in the United States, both the states and the federal government underwrite research projects; the same may be said in the case of the German Federal Republic and its constituents as well as for the situation prevailing in some Commonwealth countries, e.g., Canada and Australia. Actually, this feature appears to be quite ubiquitous, as soon as one looks below the national level: within a number of European states, notably France and Italy, the multi-layered structure of support for research activities is manifest in the co-existence of regional and national funding programs.

The existence of a supra-national governmental entity or agency that allocates public resources to R&D activities undertaken by research units throughout its domain, consequently, is not an idiosyncratic feature that is unique to EU. A widely shared feature of the situation, however, is the fact that the amount of the funding directly allocated by Europe's national entities (at the sub-ordinate governmental level) is far larger than that which the super-ordinate government authority awards to R&D projects organized in the region. Indeed, the combined level of national funding is approximately of an order of magnitude larger than the RTD (research, training and development) funds allocated by programs at the regional EU level. Thus, an obvious matter of interest for European science policy is the degree of coordination that exists between the national funding agencies and the programs devised and implemented from the European Community level, and its consequences for the effectiveness of the goals being pursued at both levels. Furthermore, there are some fundamental questions concerning the alignment of governments' policy goals that underlie many of the practical issues of implementation which, surely, will arise in regard to the recommended programs for a more coordinated approach to RTD activities under the EU Sixth Framework[10].

In the European science and technology policy context, therefore, the design of programs that provide public funding for collaborative research networks – comprised of teams that may be institutionally situated anywhere within the EU – is a key strategic vehicle which the European Commission may use to pursue R&D opportunities and challenges that transcend the particular capabilities and concerns of the individual member states. Yet, it also must be recognized that additional, more immediately instrumental considerations of a political and economic kind have shaped the terms and criteria for funding supra-national research. These transient "coalitions" are the R&D networks, and Targeted Social and Economic Research (TSER) networks that are organized within what the European Commission recently has been referring to as the "European Research Area" (ERA)[11].

By and large, the research programs sponsored by the European Commission are designed for strategic explicitly stated purposes. In some instances the aim is to change the objectives and methods of research, or to undertake socially useful lines of investigation that otherwise would be neglected; in many others, the goal is to improve European industry's international competitiveness – by inventing and developing new products and processes, or by forging links between academic and industrial research groups. Still another, more directly political motivation – that of fostering the "cohesion of Europe," by reducing disparities in its communities' scientific and technical capabilities – has figured in the implementation of some of the RTD programs organized under the aegis of the Commission[12].

[10] Major implementation issues are astutely examined in the recent NPRnet briefing paper by Steinmueller, Geuna and Salter [34]. The pragmatic approach followed in that analysis, however, is one that (doubtless, by design) thoroughly accords with the discussion style of EC public documents. Thus, it rarely averts openly to the possible existence of underlying goal conflicts among the member states, and focuses instead upon the potential manifestation of such conflicts in disagreements over the details of implementing the concept of a European Research Area. See Geuna, Salter and Steinmueller [18] for a summary statement of the particular issues of implementation which are identified as most problematic.

[11] Among recent EC documents concerning the European Research Area, see COM [13]; COM [14].

[12] The EU Human Capital and Mobility program is perhaps the one most explicitly designed

Thus, since the European Commission's inception, the collaboration among research teams drawn from more than one member country of the EU has been made a necessary condition for funding within the terms of successive European Community Framework Programmes[13]. Of course, the question remains: "collaborations of which sorts?" The EC has potentially conflicting goals regarding the criteria for selecting which among the proposed research coalitions (or "networks") will receive funding under these programs. In the near term, it seeks to raise the overall R&D productivity of the region as a whole by effectively targeting its support to the collaborative projects that appear best able to make use of the resources. But, at the same time, it has evinced a sustained interest in promoting greater "cohesion" within the European Research Area, and specifically the long-term convergence in levels of scientific and technical capability among the member states and provinces of the EU.

More than one observer of European science policy has remarked upon the potential conflict between the strategies that the EC might adopt to achieve the latter goals[14]. Were it to set the selection criteria for project funding primarily with consideration for generating high-quality research findings most efficiently, or with a view to building greater European scientific and technical capabilities on the best foundations, priority would most likely be given to proposals from research units that possessed a higher reputational standing in the relevant scientific area. In the case of network projects, it thus is possible that, with a given overall budget constraint for research funding, the Commission's goal of raising the average level of Europe's scientific and technical capabilities and performance would dictate a strategy of encouraging the strongest research institutions to work with each other. In other words, the selection criterion applied to network projects would give priority to coalitions in which the average reputation level of the members was highest.

Yet, it seems likely that a commitment to attaining that policy objective would preclude adoption of a pure "pro-cohesion" selection strategy. Under the latter, priority in the allocation of collaborative project funds would be given to proposals from networks in which the variance of the distribution of reputations (for the participating units) was greatest. By encouraging the scientifically strongest research

with such considerations in mind, but their influence extends more widely. See, e.g., the discussion by Gambardella and Garcia-Fontes [15], Garcia-Fontes and Geuna [17].

[13] On the participation of university-based research teams in the Framework programs, see, e.g., Geuna [20], chs. 6-7.

[14] See, e.g., Sharp [33].

units to collaborate with teams drawn from institutions that currently had much less elevated reputational standings, more opportunities might be created for the occurrence of the sort of knowledge and training spillovers that would promote the convergence of research capabilities across the communities of Europe[15].

Quite understandably, a considerable amount of attention has been directed to the emblematic tension between these policy objectives, and the pure strategies of implementing each in network selection criteria[16]. One might therefore anticipate that the issue will arise anew in connection with discussions of precisely how the contemplated EU Sixth Framework (2002-2006) program for funding "Networks of Excellence" should be implemented. The term "excellence" might be interpreted variously, for example, as "present scientific excellence" or as "promoting the future excellence" of European scientific research[17].

But, consideration of the matter of conflicts among R&D policy goals takes on special complexity in the European context, where, as has been pointed out, the provision of research support through the EC's collaborative programs is hardly "the only game in town." The national agencies engaged in supporting research activities also may have a variety of objectives, including the improvement of the general level of the scientific prestige and performance of the research units that are based in their respective territorial domains; or they too may be concerned to reduce internal regional disparities in their "quality," as gauged by scientific and technical capabilities. If EC and national governments choose to focus on one or the other goal, the actual joint impact of their implementation strategies might well yield unexpected outcomes – or at least outcomes that will be unexpected by the agencies if they fail to take account of each others' existence and strategy

[15] The latter proposition rests on the presupposition that all of the participating researchers would be "scientifically qualified"; not only in the sense of being able to contribute to the collaboration's scientific work, but also in possessing basic levels of training and experience needed for them to readily absorb knowledge spill-overs from all other members of their network. The degree to which such a condition actually has been met in EC Framework Programme collaborations is an interesting and potentially important policy-relevant question that deserves empirical investigation.

[16] See, e.g., the discussions by David, Geuna and Steinmueller [11], and Garcia-Fontes and Geuna [17].

[17] The discussion of implementation issues for the ERA by Geuna, Salter and Steinmueller [18] and Steinmueller, Geuna and Salter [34] suggests, by implication, that under this program the EC intends to give greater autonomy in the control of research objectives to networks formed from the leading research groups in Europe. Whether that strategy will be found to be politically implementable without reference to the national distribution of the participating teams is an issue that remains to be clarified.

choices. Correspondingly, the design of rational public funding policies in this realistically complicated context calls for explicit consideration of the effects of the activities being undertaken by the other governmental agencies that have "jurisdiction" within the territory in question.

3. A Model of Collaboration Formation with an Endogenous Externality

3.1. Notation and Key Assumptions

The model developed here is intended to capture some important elements of the way in which research collaborations form and evolve over time. Academics join departments, research groups join with other research groups in order to work on particular problems together. Part of the purpose of these collaborations can be to apply for funding toward the research undertaken together, or at least with some level of interaction to facilitate individual research. The award of external funding can produce an effect on next period's reputation of each research unit in the group. Reputation is assumed to be cumulative in this model, with reputation measured as a stock and external funding contributing to the stock.

There are a fixed set N of research units[18], indexed by $n = \{1, ..., N\}$. The research unit's size and composition depends on the particular context. A research unit may denote, for instance, a person, a research department, or an academic agency. In any one context, each research unit is taken to have the same reputation. Each research unit has a reputation at each period t, $r_n(t)$ and a reputation change denoted $\triangle r_n(t+1)$. Initial reputation is denoted as $r_n(0)$. Initial reputation is assumed to be distributed uniformly across research units. This assumption is somewhat special. However, it simplifies and extends the possible analysis. The results of the paper depend somewhat on this assumption, as they would hold for some other distributions of reputation but not all. Effects of changing this assumption are discussed with the results.

A collaboration[19] structure $\pi(t)$ is a partition on the set N. The set of all collaborations we denote by Π. A collaboration structure $\pi(t)$ consists of a set of

[18] Research units could be individuals, but for the analysis of EU research networks, they will be teams associated with educational institutions, research institutes, or firms. Research units will be interpreted as each having a single collective reputation, much as academic research departments have a single ranking relative to other departments.

[19] A collaboration is commonly called a coalition in the literature; the term collaboration is used deliberately to denote the specific type of coalition under consideration here.

$C(t)$ collaborations, indexed by $c = \{1, ..., C(t),\}$ so $\pi(t) = \{c(t)\}$. Each collaboration c contains a nonempty subset of N, consisting of $N_c(t) \geq 2$ research units. The payoff vector for each research unit in a collaboration is $\triangle r_n(t+1) : \Pi \rightarrow \Re$, where $\Re$ is the set of real numbers. A method for determining the fixed payoff to reputation will be commonly known *ex ante*. Reputation is non-transferable, as there is no bargaining over payoff division within a collaboration. For any subset K of N, the set of partitions of K is Π_K with typical element π_K.

There is a rule of order $\theta(t)$ for N, used to determine the order of moves in the sequential game of collaboration formation. This rule $\theta(t)$ specifies that the order of moves will be descending in the current reputation of each research unit. We will call the game $\Gamma(\triangle r_n(t+1), n = 1, ..., N, \theta(t))$ because collaboration formation may depend on

- the specification of reputation building, which derives from any element of Π and the implied $\triangle r_n(t+1)$ given a set N and initial reputation levels for each research unit, and
- the rule of order θ for a given set N.

3.2. External Funding Rules

Reputation building $\triangle r_n(t+1)$ is assumed to be equal to at least some minimum greater than zero, and above that it is a direct result of external funding. That is, reputation building can occur due to effort that will occur with or without the external funding, although external funding will increase the reputation building possible. External funding is measured in units of reputation.

External funding to an entire collaboration $E_c(\Pi(t))$ is non-negative and will be determined by three rules, each of which may vary as described above. These rules are set before the game begins in period 0 and they are commonly known to all research units. To repeat, these variations in the rules are:

- External funding depends on either the average reputation of a collaboration c, $\bar{r}_c(t)$, or the reputation variance, $var(r_n(t), n \in N_c(t))$, of a collaboration. Denoting the selected measure of a collaboration's reputation as $m_c(t) = \bar{r}_c(t)$ or $m_c(t) = var(r_n(t), n \in N_c(t))$, the external funding will be non-decreasing in that measure, $\frac{\partial E_c(\Pi(t))}{\partial m_c(t)} \geq 0$.
- External funding of a collaboration is defined either as per collaboration with equal distribution between research unit members or as per research

unit within a collaboration. If external funding is per collaboration, then $\frac{\partial E_c(\Pi(t))}{\partial N_c(t)} = 0$ (although it is possible that $\frac{dE_c(\Pi(t))}{dN_c(t)} \lesseqgtr 0$). Thus, as the size of a collaboration increases then, all else equal, the external funding per research unit will decrease[20]. If external funding is per research unit within a collaboration, then $\frac{\partial E_c(\Pi(t))}{\partial N_c(t)} > 0$ (and it is still possible that $\frac{dE_c(\Pi(t))}{dN_c(t)} \lesseqgtr 0$).

- External funding of a collaboration will be based on either absolute $m_c(t)$ or relative $w(m_c(t); m_k(t)\ k = 1, ..., C)$ measures of its reputation distribution, where $w(m_c(t); m_k(t)\ k = 1, ..., C)$ is the rank of collaboration c relative to all collaborations at a period t. Either $\frac{\partial E_c(\Pi(t))}{\partial m_c(t)} > 0$ if the absolute measure is used, or $\frac{\partial E_c(\Pi(t))}{\partial w(m_c(t); m_k(t) k=1,...,C)} > 0$ if the relative measure is used.

Each of the eight possible forms of external funding is analyzed and their outcomes compared.

3.3. A Description of the Collaboration Formation Game

The formation of collaborations occurs according to a non-cooperative game. An advantage of using a non-cooperative game is that it allows for explicit analysis of how collaborations form and the strategies of research units. The main drawback of using a non-cooperative game of coalition formation is that additional structure - an order of play - must be imposed on the game in order to define players' strategies. However, in the setting described here, such an order of play seems an appropriate abstraction. When forming research collaborations, it is reasonable that a research unit with a high reputation would have some ability to suggest collaborations in which that research unit would be willing to take part before other research units of lesser reputation. The structure of the non-cooperative game utilized is similar to that developed by Bloch [2]. The identifying details of the agents and the application are specific to this paper's model.

Collaborations are formed sequentially in each period t according to the game $\Gamma(\triangle r_n(t+1), n = 1, ..., N, \theta(t))$. Each player knows the reputation stocks of the set N, $\{r_n(t)\}_{n \in N}$. The first research unit according to $\theta(t)$ proposes the formation of a collaboration T to which it will belong. Each potential member of

[20] As mentioned above, it is assumed that the external funding - and thus contribution to reputation building - is split equally between the members of a collaboration. Other potential rules for splitting the funding exist, such as using a Shapley value. However, using the Shapley value, or any rule based on relative contribution to collaboration's funding, is not possible in this model. This is because relative contribution is not determinable for most or all cases.

T responds to the proposal in the order given by $\theta(t)$. If one player rejects the proposal, it makes a counteroffer and proposes a collaboration T' to which it will belong. If all potential members accept, the collaboration is formed. All members of T would then form the collaboration and leave the game, and the first research unit in $N \backslash T$ according to $\theta(t)$ makes a proposal. Note that once a collaboration is formed, the game is then played only by the remaining players. Once a player joins a collaboration, it cannot leave or propose to change the collaboration in that period[21]. The game is completed in a period t when either all research units are part of a collaboration, or when none of the remaining research units are willing to propose a collaboration.

A history of the game $h_v(t)$ at stage v in period t is a list of offers, acceptances and rejections up to stage v in period t. A history thus implies: the set $\hat{K}(h_v(t))$ of research units who have formed collaborations, the coalition structure $\pi_{\hat{K}(h_v(t))}$ formed by those research units, any ongoing proposal $\hat{T}(h_v(t))$, a set of research units who have accepted the ongoing proposal, and which research unit proposes at stage v.

A research unit n is active at history $h_v(t)$ if it is its turn to accept/reject or propose after the history $h_v(t)$. The set of histories at period t at which a research unit n is active is $H_n(t)$. A strategy $\sigma_{vn}(t)$ for a research unit n is a mapping from $H_n(t)$ to its set of actions, that is

$$\sigma_n(h_v(t)) \in \{Yes, No\} \text{ if } \hat{T}(h_v(t)) \neq \emptyset$$

$$\sigma_n(h_v(t)) \in \left\{T \subset LS \backslash \hat{K}(h_v(t)), j \in T\right\} \text{ if } \hat{T}(h_v(t)) = \emptyset.$$

If $\hat{T}(h_v(t)) \neq \emptyset$ then research unit n must accept or reject the ongoing proposal. If $\hat{T}(h_v(t)) = \emptyset$ then research unit n is the first research unit in $N \backslash \hat{K}(h_v(t))$ according to the order rule $\theta(t)$ or else research unit n has just rejected a proposal and it must now propose a new collaboration.

A strategy profile $\sigma(t) = \{\sigma_n(t)\}_{n \in N \backslash K}$ determines the outcome $\pi(\sigma(t))$.

[21] As noted earlier, no bargaining within a cluster can occur due to the non-cooperative framework and the absence of an enforcement mechanism. For a model of coalition formation with intra-coalition bargaining, see Ray and Vohra [32].

3.4. Equilibrium Definition and Properties

We now clarify the concept of equilibrium in this model. The payoff for a research unit n is given by

$$\triangle r_n(t+1) = \max_{\pi} \triangle r_n(\pi) = \triangle r_n(E_c(\Pi(t))\,;\; n \in c)\, \forall n \in N.$$

A subgame perfect equilibrium $\sigma^*(t)$ is a strategy profile such that $\forall n \in N$, $\forall h_v(t) \in H_n(t)$, $\forall \sigma_n(t)$, $\triangle r_n\left(\pi\left(\sigma_n^*(t), \sigma_{-n}^*(t)\right)\right) \geq \triangle r_n\left(\pi\left(\sigma_n(t), \sigma_{-n}^*(t)\right)\right)$.

Proposition 2.1 There exists a subgame perfect equilibrium of the game

$\Gamma(\triangle r_n(t+1), n = 1, ..., N, \theta(t))$.

Proof This result follows directly from Bloch [2]: Proposition 2.4 and Corollary 2.5.■

This result is proved by Bloch by showing first that in a game with sufficient time discounting, a subgame perfect equilibrium will exist because players' payoffs will decrease if they wait too long before settling on an outcome. It is then shown that a subgame perfect equilibrium with sufficient time discounting is also a subgame perfect equilibrium of the game $\Gamma(\triangle r_n(t+1), n = 1, ..., N, \theta(t))$.

3.5. Equilibrium Collaborations

The selection criterion of a given "funding "regime" is defined according to whether the agency will assign priority scores to collaborations according to the average (or the variance) of the partners' reputational standings, and will allocate funds on the basis of these absolute scores (or the coalitions' relative rankings). Combining the binary variants of these two dimensions of the funding regime with the pair of alternative budget-setting rules (fix either the level of funding per collaboration, or per research unit participating in the collaboration), there are eight different cases of the funding regime to be considered.

For each of these cases the object of this stage of the analysis is the same: to describe the pattern of endogenous coalition formation that represents an equilibrium at a given moment of time, and then to track how that pattern will be modified over time as the effects of funding allocations, and the research outcomes they permit, alters the reputational distribution in the population of research units.

Comparisons of the way that the funding regime's institutional features affects the distribution of reputed research competence is then possible, albeit in a high stylized sense. Do some sets of funding rules result in a tendency toward reputational convergence within the population as a whole, whereas the effect of other rules is an increase in the variance of the distribution of reputations in absolute terms, or possibly also in relation to the mean of the distribution? Also of interest is the question of whether the equilibrium coalitional is unique for some funding regimes, and whether a multiplicity of equilibria exist in other cases. Then there is the question of the influence of the funding regime's features upon the size of the equilibrium coalition(s) whose formation it will induce: is the number of partners tightly circumscribed by a given regime, or can it vary widely?

In Table 1 the eight variants we have considered are identified and assigned "case" numbers, which are used, in turn, by Table 2 to label the summary of the analytical results. The details of the analysis are presented for all eight cases in the Appendix: 7.Equilibria of the Coalition-Formation Game with a Single Funding Agency, sections 7.1 -7.8. From the tables it may be seen immediately that the answer to the questions posed above in every instance is: "yes." In 6 of the eight cases the size of the equilibrium structure of the induced coalitions is tightly circumscribed, at 2 partners; and in 4 or those 6 the equilibrium structure is uniquely defined. But there are 4 other cases in which a multiplicity of equilibria exists, and for 2 among those more than one coalition size is possible. In 4 of the 8 cases the absolute variance of the reputation-measure among the research units in the population will be increasing unambiguously from one round of the funding competition to the next, but the ordering of reputational standings remains undisturbed. But in the other half of the cases, their can be "leapfrogging" - in which some units surge upwards in the reputational rankings, while others drop behind. In some instances this can result in convergence in the distribution[22].

4. The Formation of Supra-national Research Networks

In the model of collaboration formation, when the research funds are allocated toward the highest average reputation collaborations, then the collaboration pattern is a partition of disjoint subsets along the reputation distribution. Further, the variance will unambiguously increase. When the research funds are allocated toward the highest reputation variance collaborations, then the collaboration pat-

[22] The reader is referred to Appendix 7 for further elucidation of the complex forces that give rise to these varied results. In some instances it is not possible to determine, without additional specification of the model, whether the variance (and the rel-variance) tend to increase, or not with the repetition of the funding process

tern is no longer a partition and leapfrogging in the reputation distribution becomes possible. The overall variance may not increase.

When funding is allocated on a fixed per collaboration basis, then the equilibrium collaboration size is always the minimum of 2. When funding is allocated per unit, then collaborations become insensitive to the size of the collaboration, and so larger collaborations are possible in equilibrium.

Lastly, if funding is allocated based on a collaboration's absolute measure of average reputation or reputation variance, then the collaboration equilibrium is unique. On the other hand, if funding is allocated solely on the basis of the networks' respective rankings according to which ever measure is appropriate for the agencies' goals, then a multiplicity of equilibria appears in the array of networks which can be formed.

It is of some interest to ask which, among the variety of stylized funding regimes just considered, is the one that should be thought to most closely resemble the general features of recent EU funding for RTD under the Economic Commission's Framework Programmes. Two quite different approaches might be taken to answering this question. One might try to extract the essentials of the complex and not always transparent process of allocating grants and contracts, or, alternatively, make use of the implications of the theoretical model of research coalition formation to extract inferences about the salient characteristics of the regime - reasoning backwards from empirical observations about the outcomes of the operations of these R&D programmes. We take the second option, partly because the purpose here is not to detail the administrative realities of EU R&D funding. A further reason is that, as will be seen, the juxtaposition of available empirical observations and the coalition formation model's implications serves to underscore several respects in which the highly stylized nature of the model limits its direct applicability for the task of designing funding policies in the European Research Area.

A number of empirical points may be cited in support of the argument that publicly funded trans-national research collaborations in Europe resemble those that, on theoretical grounds, would be expected to form in a "regime" corresponding to Case 1: funding priority given to collaborations with higher average reputational standing, allocation of funds on the basis of absolute reputational scores, and budget rules that fix the level of funding per collaboration (rather than per partner).

First, the pattern of concentration, or left-skewness, in the distribution of R&D output (such as publications and patents), is evident among European research institutions. A small proportion of research units contribute a large proportion of the research results, just as a small proportion of individual researchers are found to be (at least nominally) responsible for the majority of scientific and technological publications (see David [7]). This may be in part due to the information signalling problem that affects funding decisions: funders may use past success as a signal of future potential success. This criterion leads to the familiar cumulative advantage phenomenon associated with the Matthew Effect in science. The application of such a criterion may not bestow support upon those research institutions that actually have the greatest research productivity potential for the program in question. Nevertheless, being able to achieve more funding may allow institutions with strong reputations to draw support, and thus reinforce stratification rather than convergence within the distribution of Europe's research units.

The Matthew Effect is consistent with the average reputation funding rule, that implies an increased variance in the reputation distribution. It is also consistent with the use of an absolute measure of average reputation, as the unique equilibrium implies persistence in the units that are funded via collaboration.

Second, the determinants of participation in the European research coalitions that receive EC funding have been identified in empirical work (see Geuna [19]). Past research success, consistent with the Matthew effect, appears to be a main indicator. Larger and older universities, in particular, have a higher participation rate in these coalitions than other universities. Finally, country effects appear to be important - some countries (such as Ireland) have a higher rate of participation than others (such as France).

The influence of past research success also supports the use of an absolute measure of average reputation, as use of this measure implies persistence in the distribution of reputation.

Third, the types of participants have changed over time. There has been increased homogenization of research institutions over time, the variety of institutions has decreased. The size of the coalitions has decreased over time. (For details of this, see Garcia-Fontes and Geuna [17]).

An increase in the homogeneity of funded research units is, again, consistent with persistence in the units that are funded over time. Persistence is a result of a unique equilibrium, as when the absolute level of average reputation is used to determine funding[23]. The decrease in the number of institutions corresponds

[23] Partially weakening this conclusion is evidence that the internal structure of the coalitions has changed over time. The proportion of small, less well-known, research institutions in the coalitions has increased. The coalitions have internally seemed to exhibit competitive rather

with a move from funding per unit to funding per collaboration.

The obvious trouble with the foregoing inferences is that, as may be seen by consulting Table 2, the implication of the funding regime corresponding to Case 1 is that the equilibrium size of the coalitions should never exceed 2 partners[24]. Yet, both from casual observation and from the systematic studies (by Garcia-Fontes and Geuna [17] and Geuna [19]) of the participation of university-based research units in EU Framework Programmes, it is apparent that there typically are many more than 2 partners. Indeed, that is the case even within the recurring sub-groups of "core partners" ("network clusters") that are found to have drawn funding from the successive Framework Programmes.

What the foregoing discrepancy suggests is the those who take the leading in the coalition formation process give due weight to the possibility that other criteria may enter into the process of project selection, so that their own expected funding awards may be raised by the recruitment of additional partners even though doing so tends to reduce the average partner's share of the amount awarded. Inasmuch as many of the research problems undertaken call for a variety of technical skills and expertise, and the population of potential partners is heterogeneous in this respect, this is hardly surprising. It also is reasonable to suppose that applicants for funding do not presume to know with certainty the relative weights that will be given to the various selection critieria in the funding process; rather than "optimize" on the basis of false certainty, the coalition members are buying a form of "insurance" by enlarging their collaboration by the inclusion of a more diverse collection of partners whose presence augments the attractiveness of the ensemble to the funding agency. These considerations, however realistic, lie beyond the reach of our present modelling efforts. By the same token, they indicate the

than cooperative behavior in the division of rewards and in the research process. Nevertheless, the level of technology "spill-ins" within the coalition appears to have increased.

In the collaboration model, the churning that occurs in the cases where relative ranking occurs is roughly consistent with this empirical evidence. However, the other evidence described in the body of the paper all points toward an absolute measure.

[24]EC funded R&D collaborations that are engaged in pre-market research ("indirect actions") have been permitted to have as few as two partners, under the terms of the Framework Programmes up to and including the Fifth Framework (1998-2002). This will continue to be the case under the Sixth Framework (2002-2006), except for the newly introduced "networks of excellence," which must have 3 partners, at least 2 from EU member states. The proposed "networks of excellence" represents a radically new mode of funding for the EU, and a departure from the model based upon historical experience, in that it allows non-EU participation, provides contractual flexibility to permit new partners to enter, and original partners to withdraw from these longer-lived collaborations.

limits of applicability of the findings as a basis for advancing specific institutional policy designs.

5. A Model of National and Supra-national Research Funding

A model of national and supra-national research funding is now developed to determine how the funding rules of these two types of institutions interact. The effects on the distribution of reputation both within nations and supra-nationally are analyzed. Different rule combinations on the distribution will be compared.

Behind each of these rules is a goal of each funding agency; rules will be chosen in light of those goals. It is possible to evaluate each agency's rule choice given the goal of that agency and the goals and rules of the other institutions. After a general analysis under each possible combination of rules is presented, an example will be developed. This example will allow for more exact comparison of different combinations of rules, in order to determine which rules will be equilibrium strategies for each agency in light of the goals of each agency. These results are used to suggest how national and EC funding institutions should approach funding research. Equilibrium rules are determined in order to draw general lessons for how the national and supra-national institutions should fund R&D in the presence of each other.

It may be noted that the "either/or" formulation is a convenient simplification that allows us to assess the contrasting effects of the extremal criteria, so long as it corresponds to the set of beliefs about the agency's goals that are held among the research units when they consider forming collaborations to seek funding. But to the extent that there is uncertainty as to which of the extrema (max the average, vs. max the variance) actually best characterizes the funding agency's selection criterion, then the characteristics of the coalitions that formed would differ from those indicated by our model, and the results of the analysis would be correspondingly altered.

In this model, the supra-national agency will continue to fund collaborations, but these collaborations must include research units from more than one nation. National institutions will fund individual research units within their national borders. Each agency will have a goal that it is trying to achieve through its funding. This goal will be either to improve the average reputation of its research constituency, or to decrease the variance in reputation of its research constituency.

These goals correspond to the two stated goals of the EC, described in the Introduction and Section 2.

It is assumed that there are two nations, indexed by 1 and 2. They have the same number of research units in each, $N_1 = N_2$, and $N_1 + N_2 = N$ is the total number of research units in the economy. Research units $n \in [1, ..., N]$ are ordered by their reputation and their reputation will be uniformly distributed. In particular, all nation 2 units will be assumed to have a higher reputation than all nation 1 units: $r_n > r_m$, $n \in [N_1 + 1, ..., N]$, $m \in [1, ..., N_1]$.

The number of collaborations funded k will be assumed small relative to the total number of research units in each nation. The funding per research unit from a collaboration will be assumed larger than the national funding per research unit. However, the total amount of funding from collaborations is assumed smaller than the total funding from national institutions, in accordance with empirical evidence referred to in the Introduction and Section 4.

It will be taken as given that collaborations are funded on a per collaboration basis and based on an absolute measure of the collaboration's reputation average or variance. Therefore, as follows from the analysis detailed in the Appendix (subsection 6.1, especially) and summarized by Table 2, a unique set of collaborations, each having exactly 2 partners will be formed, and a subset of them will be selected to receive funding according to the criteria of the national and supra-national agencies.

Funding from supra-national institutions and from national institutions will determine the change in reputation for each research unit, Δr_n. The magnitude of the effect of the collaboration c on the increase in average reputation level depends on the functional relationship between the reputation average of a collaboration and its funding level $E_c(\Pi(t))$, and the functional relationship between the funding level and reputation building $\triangle r_n (E_c(\Pi(t))\,;\; n \in c)$. If there is a constant returns relationship in both cases, then the size and number of collaborations will not affect the rate of increase in the overall average reputation level of research units. Empirical evidence from Arora, David and Gambardella [1] suggests the effect of reputation level on the change in reputation level exhibits diminishing returns.

Therefore, this assumption will be adopted; funding will be assumed to have a diminishing returns effect on Δr_n. However, this diminishing returns will be of a special type. It will also be assumed that collaboration and individual funding will increase in the absolute level of the reputation of the funded unit(s). Funding will increase by reputation in such a way that the change in reputation for all units receiving the same type of funding (or both types) will be equal. In other words, Δr_n can be identified from the source of research funding only. The change in reputation due to research funding to a unit from a collaboration will be denoted as Δr_H; from a national source as Δr_L. In the case that neither source of funding is received, it will be assumed that the change in reputation is equal to v :

$$\Delta r_H > \Delta r_L > v.$$

Several combinations of funding rules are to be considered and compared. First, as has been alluded to, the supra-national agency will fund k collaborations that have either the highest average reputation or the highest reputation variance. Each national agency can follow three main rules: it can fund individual research units independently of the funding decision of the supra-national agency, it can fund only research units that have not been funded by the supra-national agency, or it can fund only research units that have been funded by the supra-national agency. If research units are funded independently by the national agency, then it will fund all equally, or fund only the top half of the reputation distribution, or fund only the bottom half of the reputation distribution. It will be assumed that all national institutions follow the same funding rule.

5.1. The Interaction of National and Supra-national Funding Regimes

The possible combinations of national and supra-national funding rules generate 10 different "mixed funding regimes," each constituting a case that must be examined in turn. The first of these is exhibited in the text below, with the explanatory Figure 1, in order to give the reader the flavor of the calculations that are involved in determining the outcome of the interactions between the funding rules and the equilibrium coalitions whose formation they induce. Details of the remaining (nine) cases, some of which are considerable more complicated, may be followed in the appendix of Section 7.

Before funding takes place, the initial averages and variances in reputation for each nation and for the entire economy are:

$$\bar{r}_1 = \frac{\sum_1^{N_1} r_n}{N_1}; \bar{r}_2 = \frac{\sum_1^{N_2} r_n}{N_2}; \bar{r} = \frac{\sum_1^{N} r_n}{N}$$

$$Var_1 = \frac{\sum_1^{N_1} (r_n - \bar{r}_1)^2}{N_1}; Var_2 = \frac{\sum_1^{N_2} (r_n - \bar{r}_2)^2}{N_2}; Var = \frac{\sum_1^{N} (r_n - \bar{r})^2}{N}.$$

The possible combinations of national and supra-national funding rules are now considered in turn.

1. The national agency funds independently of the supra-national agency decision

A. The national agency funds all research units in the nation to produce an equal change in reputation

i. The supra-national agency funds the k highest average reputation collaborations

This case is depicted in Figure 1, explaining which units are funded and what their resulting change in reputation is. The illustration is used to calculate the new averages and variances. The new average for each nation is clearly higher:

$$\bar{r}_{1A} = \frac{\sum_1^{N_1} r_n}{N_1} + \frac{\left[\left(N_1 - k\right)\Delta r_L + k\left(\Delta r_H + \Delta r_L\right)\right]}{N_1};$$

$$\bar{r}_{2A} = \frac{\sum_1^{N_2} r_n}{N_2} + \frac{\left[\left(N_2 - k\right)\Delta r_L + k\left(\Delta r_H + \Delta r_L\right)\right]}{N_2};$$

the new overall average is

$$\bar{r}_{A} = \frac{\sum_1^{N} r_n}{N} + \frac{\left[\left(N - 2k\right)\Delta r_L + 2k\left(\Delta r_H + \Delta r_L\right)\right]}{N}.$$

The new variance for each nation is also unambiguously higher:

$$Var_{1A} = \frac{\sum_1^{N_1}\left(r_n - \bar{r}_1\right)^2}{N_1} + \frac{\sum_1^{N_1}\left(\Delta r_n - \Delta\bar{r}_1\right)^2}{N_1} + \frac{2\sum_1^{N_1}\left(r_n - \bar{r}_1\right)\left(\Delta r_n - \Delta\bar{r}_1\right)}{N_1}; \tag{5.1}$$

$$Var_{2A} = \frac{\sum_1^{N_2}\left(r_n - \bar{r}_2\right)^2}{N_2} + \frac{\sum_1^{N_2}\left(\Delta r_n - \Delta\bar{r}_2\right)^2}{N_2} + \frac{2\sum_1^{N_2}\left(r_n - \bar{r}_2\right)\left(\Delta r_n - \Delta\bar{r}_2\right)}{N_2}; \tag{5.2}$$

and the new overall variance is also unambiguously higher:

$$Var_{A} = \frac{\sum_1^{N}\left(r_n - \bar{r}\right)^2}{N} + \frac{\sum_1^{N}\left(\Delta r_n - \Delta\bar{r}\right)^2}{N} + \frac{2\sum_1^{N}\left(r_n - \bar{r}\right)\left(\Delta r_n - \Delta\bar{r}\right)}{N}. \tag{5.3}$$

In particular, it is straightforward to show that the third terms of the right-hand side of (5.1), (5.2), and (5.3) are positive.

5.2. A Numerical Example

These 10 cases are exemplified through specific assumptions on the variables. The main purpose of using an example is that comparisons between the effects of the rule combinations is simple. It is possible to determine the best strategies to be chosen by each funding agency given its goal and the goal of the other institutions.

The assumptions used in the example are as follows. The size of the two nations are $N_1 = N_2 = 100$; the number of collaborations funded by the supra-national agency is $k = 15$. The initial reputation distributions across the two nations are uniformly distributed and disjoint: $r_n < r_m \; \forall n \in N_1,\; m \in N_2$. In particular, $r_n \in [50, 149]$ and $r_m \in [150, 249]$. The effect of funding on reputation from the different types of funding are:
$\Delta r_H = 10$ from supra-national agency funding of collaborations, $\Delta r_L = 5$ from national agency funding of individual research units, and the change in reputation is $v = 2$ if there is no funding from either source. The results of this example under each case are summarized in Table 3 and in Tables 4A, 4B, and 4C.

Using these tables, a Nash equilibrium for each set of institutional goals can be determined. If the supra-national agency wants to maximize the increase in the overall reputation average, and the national institutions each want to maximize the increase in their national reputation average, then the Nash equilibria correspond to each national agency funding all of its research units equally, and the supra-national agency funding either the highest average collaborations, or the highest variance collaborations (cases 1Ai and 1Aii). These strategies not only correspond to Nash equilibria, they also result in the best possible outcomes for each agency *given their goals*.

In the case where the supra-national agency's goal is to minimize variance and the national institutions' goals are to minimize their national variances, the strategies (rules) in Nash equilibrium are for national institutions to fund the bottom half of the research unit reputation distribution, and for the supra-national agency to fund the k highest variance collaborations. The Nash equilibrium represents the best possible outcomes for all of the institutions given their goals.

The Nash equilibrium strategies are the same in the case where the supra-national agency's goal is to maximize the overall average reputation, while each nation's goal is to minimize the national variance of reputation. The Nash equilibrium results in the best possible outcome for the national institutions, but not for the supra-national agency.

When the supra-national agency's goal is to minimize overall variance and the national institutions' goals are to maximize their national reputation averages, then the Nash equilibrium strategies are for the supra-national agency to fund the top k variance collaborations, and for the national institutions to fund all of its research units equally. This Nash equilibrium again provides a best possible outcome for the national institutions, but not for the supra-national agency.

These equilibria can be summarized in the following way: the supra-national agency should always choose to fund the top k variance collaborations regardless of the goals of each agency. The national agency should fund all of its research units equally when its goal is to maximize its national reputation average, and should fund the bottom half of its research units when its goal is to minimize its national reputation variance. The national agencies rules hold regardless of the rule adopted by the supra-national agency.

As a check on robustness, several related exercises are carried out. In short, the result of these exercises is that the results reported above are indeed robust to several alternative assumptions. Alternative assumptions on the initial distribution of reputations were considered. Both overlap across the two nations' distributions and left-skewness in each nation's distributions were considered. These alternatives do not change the results. Altering the measurement of reputation and change in reputation by using the natural log of each value does not change the results (see Tables 5A, 5B, and 5C). Variations in k, the number of collaborations funded by the supra-national agency, do not affect the results so long as k is not too large. When k is large (75 or larger) then the results affected are those of the variance/(mean squared) variable only (see Table 3), which is not a variable focused on in our analysis.

The use of the variance of reputation, rather than the variance/mean, for the analysis, may be subject to question. Again, in terms of the results, use of one or the other does not alter our conclusions. This is clear from Tables 3 and 4A-4C. Conceptually, it is the view of the authors that the use of variance is appropriate for at least two reasons. First, variance in reputation here is used to capture inequality in reputation. Controlling variance by the mean causes inequality to be measured relative to reputation level. It is not clear that this is desirable in the abstract, nor what policymakers have in mind. Consider discussions of income inequality. There, a commonly used measure of inequality is the Gini coefficient which, like variance, does not control for the level of income. Gini coefficients are compared across countries with very different average per capita incomes. Thus, there is precedence for using measures of inequality that do not control for the level of the variable considered.

There is also a connection between the measure of cohesion of research units and assumptions regarding spillovers across research units that collaborate. Implicitly, we have assumed diminishing returns to research funding that depend only on a research unit's own reputation level, and not those of its collaborators. This can be interpreted as assuming spillovers across research units that depend only on the level of supra-national funding and not on the initial levels of reputation. This is where the use of variance or variance/mean as a measure of cohesion comes into question. The use of variance alone implicitly allows for spillovers to be independent of the level of reputation and to depend only on the collaboration funding. The use of variance/mean implicitly assumes that spillovers will depend on the level of reputation, that it will be easier for a research unit to increase a given amount, all else equal, if its initial reputation is higher. To repeat, this issue is important theoretically. However, its impact in practice is negligible, as our example's results are not dependent on the use of variance, as opposed to variance/mean, to measure cohesion of reputation across research units.

5.3. Discussion

This analysis presents three general results. First, it is clear that each agency's outcome depends on its strategy (its rule) and the other institutions' strategies (their rules). Second, in the Nash equilibrium it will either be the case that the supra-national agency does not realize its best possible outcome given its goal but the national institutions do, or that all three institutions do. Third, although each national institution's optimal strategy changes given its goal, that national agency will always be able to achieve its best possible outcome, while the supra-national agency will be able to do so only when the goals are of the same type across institutions.

The national agency never finds it an optimal strategy to choose its funding based on the funding rule of the supra-national agency. Rather, it should choose its funding rule independently of the funding choice of the supra-national agency. This result is important in light of evidence that countries, such as the UK, determine which national researchers to fund based on which obtain EC funding. The analysis suggests that such a strategy is not optimal for the UK as a whole, regardless of its ultimate goal.

The supra-national agency may state that its objective is not (only) to minimize the variance but to maximize the overall average reputation. The analysis predicts that which objective the supra-national agency has should not change its strategy, it can always fund the top k reputation variance collaborations. However, even if the national institutions misread this statement to mean that the supra-national agency is going to fund the top k average reputation collaborations, then the national institutions will still choose the same strategy as that of the Nash equilibrium. Therefore, the potential conflict between EC objectives, described in the Introduction, does not present itself in terms of adoption of strategy.

6. Conclusion

This paper sets out a framework to model collaboration formation in a setting of research funding that depends on the collaboration characteristics. The results of this model are used to analyze a setting in which national and supra-national institutions fund researchers. Their goals and strategies interact to yield particular Nash equilibria. The purpose of such a model is to provide a framework in which to discuss the formation and funding of research networks by a supra-national agency, such as the EC, in light of the existence of national funding entities that may be pursuing their own objectives.

The conclusion of the analysis conducted in this particular exercise is that, regardless of whether the supra-national agency's underlying objective is to raise the overall level of R&D capabilities and hence of the average scientific standing of the research units within its domain, or to promote greater coherence (in the sense of convergence) among the capabilities of its research units, the stated rule it should adopt is to give funding priority to the proposed collaboration that has the highest variance in the reputational standings of its members. The supra-national agency's optimal strategy in this regard is not only independent of the weight it assigns to the seemingly conflicting policy goals of ("excellence" vs. "coherence"); it also is independent of the strategies being followed by the national agencies.

The response of the national institutions will depend on their own national objectives. However, the national institutions should fund their own researchers based on rules that do not depend on the funding decisions of the supra-national agency. Rather, the national rules should be free-standing.

Some more obvious, and perhaps more robust conclusions also follow from the analysis. Endogenously formed research networks constrain the selections that funding agencies are able to make without directly intervening in the network-building process. The policy goals of a supra-national funding agency may be more fully attained if it is able to influence the policies of national funding bodies, but discourage them from adopting strategies that cause national funding policies to change if the supra-national funding goal changes. As a rule, however, taking explicit account of the co-existence of a multiplicity of funding agencies introduces significant complications, and raises awareness for policymakers of the likelihood of the interdependence of funding strategies and outcomes. Understanding these complications is not possible within the terms of the traditional analysis of the economics of R&D project choice, where the array of alternative projects is presumed to be independent of the funding criteria - just as the shape of the marginal efficiency of investment schedule is presumed to be independent of the rate of interest. Where the projects that present themselves for selection are endogenously formed, those that present themselves will both reflect expectations about the intentions and constraints under with the funding agency is operating, and, in turn, constrain the choices that are available to it. This mutual interdependence will, of course, be all the greater in the absence of effective competition for projects among diverse funding agencies.

Both difficult challenges and important opportunities are presented for further theoretical and empirical study of the economics of research networks. Clearly, further work is necessary to understand the institutional intricacies that result in the funding of research in the EU today. Nonetheless, the results of this simple model are quite clear, and suggest that the current strategies of the EC and national R&D funders may not be their best possible strategies. The national strategies, in the presence of a supra-national agency's funding, appears to be the place where concern should focus particularly.

This paper has provided only a heuristic aid to thinking about quite complicated class of problems public finance economics to tackle. But, it has not escaped our notice that the scope for application of the modeling approach taken here is considerably broader than might be suggested by confining our discussion to the provision of public funding for R&D, by a multiplicity of agencies with overlapping spheres of action. Generically, the issues addressed here are ones that will be seen arise to federal systems where local fiscal entities are able to form coalitions in order to compete for funding from the centre, and where receipt of such funding enhances the attractiveness of those entities as partners in future fund-seeking coalitions.

References

[1] Ashish Arora, Paul A. David, and Alfonso Gambardella. Reputation and competence in publicly funded science: Estimating the effects on research group productivity. *Annales D'Economie et de Statistique*, 49/50, 1998.

[2] Francis Bloch. Endogenous structures of association in oligopolies. *RAND Journal of Economics*, 26(3):537–556, 1995.

[3] M. Callon. Four models in the dynamics of science. In S. Jansanoff et al, editor, *Handbook of Science and Technology Studies*. Sage, 1995.

[4] M. Callon and A. Rip, editors. *Mapping the Dynamics of Science and Technology*. MacMillan Press, 1986.

[5] R. Coombs, A. Richards, P. Saviotti, and V. Walsh, editors. *Technological Collaboration: The dynamics of cooperation in industrial innovation*. E. Elgar Press, 1996.

[6] Partha Dasgupta and Paul A. David. Toward a new economics of science. *Research Policy*, 23:487–521, 1994.

[7] Paul A. David. Positive feedbacks and research productivity in science: Reopening another black box. In O. Granstrand, editor, *Economics of Technology*, pages 65–89. Elsevier Science, 1994.

[8] Paul A. David. Common agency contracting and the emergence of 'open science' institutions. *American Economic Review*, 88(2), 1998.

[9] Paul A. David. Communication norms and the collective cognitive performance of 'invisible colleges'. In G.Barba Navaratti et al, editor, *Creation and Transfer of Knowledge: Institutions and Incentives*. Springer-Verlag, 1998.

[10] Paul A. David. From keeping "nature's secrets" to the institutionalization of "open science". Discussion Paper 23, Oxford University Discussion Papers in Social and Economic History, March 2001.

[11] Paul A. David, Aldo Geuna, and W. Edward Steinmueller. Additionality as a principle of European R&D funding. *MERIT Research Memorandum*, (2/95-012), 1995.

[12] H. Etzkowitz and C. Kemelgor. The role of research centres in the collectivization of academic science. *Minerva*, 36:271–288, 1998.

[13] COM 612 final. Making a reality of the European research area: Guidelines for EU research activities (2002-2006). Report, 2000.

[14] COM 94 final. Proposal for a decision of the European parliament and the council concerning the multi-annual framework program 2002-2006. Report, 2001.

[15] A. Gambardella and W. Garcia-Fontes. Regional linkages through European research funding. *Economics of Innovation and New Technology*, 4(2):123–138, 1996.

[16] A. Gambardella and F. Malerba, editors. *The Organization of Economic Innovation in Europe*. Cambridge University Press, 1999.

[17] Walter Garcia-Fontes and Aldo Geuna. The dynamics of research networks in europe. In Alfonso Gambardella and Franco Malerba, editors, *The Organization of Economic Innovation in Europe*. Cambridge University Press, 1999.

[18] A. Geuna, A. Salter, and E. Steinmueller. Towards a new era in research. *Science and Public Affairs*, pages 25–26, June 2001.

[19] Aldo Geuna. *The Economics Of Knowledge Production: Funding and the Structure of University Research*. Edward Elgar, 1999.

[20] Aldo Geuna. Patterns of university research in Europe. In Alfonso Gambardella and Franco Malerba, editors, *The Organization of Economic Innovation in Europe*. Cambridge University Press, 1999.

[21] D. Hicks and J. S. Katz. Science policy for a highly collaborative science system. *Science and Public Policy*, 23(1):39–44, 1996.

[22] J. S. Katz. Geographical proximity and scientific collaboration. *Scientometrics*, 31(1):31–43, 1994.

[23] J. S. Katz and B. R. Martin. What is research collaboration? *Research Policy*, 26(1):1–18, 1997.

[24] Louise C. Keely. Exchanging good ideas. Working paper, University of Wisconsin, November 2000.

[25] B. Latour. *Science in Action: How to follow scientists and engineers through society*. Harvard University Press, 1987.

[26] B. Latour and S. Woolgar. *Laboratory life: The Construction of Scientific Facts*. Princeton University Press, 1986.

[27] Robert K. Merton. The matthew effect in science. *Science*, 159:56–63, 1968.

[28] Robert K. Merton. *The Sociology of Science*. University of Chicago Press, 1973.

[29] D.C. Mowery. Collaborative R&D: How effective is it? *Issues in Science and Technology*, Fall:37–44, 1998.

[30] D.C. Mowery, J.E. Oxley, and B.S. Silverman. Strategic alliances and interfirm knowledge transfer. *Strategic Management Journal*, 17:77–92, 1996.

[31] Debraj Ray and Rajiv Vohra. A theory of endogenous coalition structures. *Games and Economic Behavior*, 26:286–336, 1999.

[32] Debraj Ray and Rajiv Vohra. Coalitional power and public goods. Working paper, New York University and Brown University, August 2000.

[33] M. Sharp. Competitiveness and cohesion: Are the two compatible? *Research Policy*, 27(6):569–588, 1998.

[34] Edward W. Steinmueller, Aldo Geuna, and Ammon Salter. Implementing the european research area. Issues brief, NPRnet, SPRU-Science and Technology Policy Research, University of Sussex, April 2001.

[35] Paula E. Stephan. The economics of science. *Journal of Economic Literature*, 34(3):199–235, 1996.

[36] Paula E. Stephan and S.G. Levin. The critical importance of careers in collaborative scientific research. *Revue d'Economie Industrielle*, 79:45–61, 1997.

7. Appendix: Equilibria of the Coalition-Formation Game with a Single Funding Agency

7.1. Case 1

The measure of collaboration rank is the average collaboration reputation; external funding is determined per collaboration; external funding

per collaboration is based on the absolute measure:

$$m_c(t) = \bar{r}_c(t)\,; \frac{\partial E_c(\Pi(t))}{\partial N_c(t)} = 0; \frac{\partial E_c(\Pi(t))}{\partial m_c(t)} > 0.$$

Equilibrium collaborations will be size 2 for two reasons: the division of the external funding between collaboration members and the desire of potential collaboration members to maximize the reputation building via maximizing external funding. Because the measure is absolute, there will be no multiplicity of equilibria. Collaborations will be proposed and accepted that are of the two highest reputation level units still in the collaboration formation game.

This collaboration formation pattern will persist over time. The variance over the distribution of research unit reputation is increasing over time, as shown below. The increase in variance does not depend on an initial uniform distribution of reputation. The average reputation level of all research units will be increasing.

The collaboration formation pattern is size 2, with persistence in the collaboration pattern and collaborations form in order of reputation level. The variance is shown to be increasing between any two periods for the general case of $\frac{k}{2}$ collaborations (k research units). The variance is increasing if the following expression holds:

$$\sum_{i=1}^{k} \left(X_i - \bar{X}\right)^2 < \sum_{i=1}^{k} \left(X_i + Y_i - \bar{X} - \bar{Y}\right)^2$$

where X_i is the original reputation of research unit i, Y_i is the reputation building of research unit i as a result of participating in a collaboration, and $\bar{X}$ and $\bar{Y}$ are the corresponding averages across all research units. The expression reduces to:

$$0 < \sum_{i=1}^{k} \left(Y_i - \bar{Y}\right)^2 + 2\sum_{i=1}^{k} \left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right).$$

The first term on the right hand side is clearly positive. The second term on the right hand side will also be positive because the collaborations form in order of reputation. If $X_i > \bar{X}$, then $Y_i > \bar{Y}$ because of the ordering of the collaborations. If $X_i < \bar{X}$, then $Y_i < \bar{Y}$ by the same reasoning. Therefore, the expression must hold and so the variance is increasing.

7.2. Case 2

The measure of collaboration rank is the average collaboration reputation; external funding is determined per research unit; external funding

per collaboration is based on the absolute measure:

$$m_c(t) = \bar{r}_c(t); \frac{\partial E_c(\Pi(t))}{\partial N_c(t)} > 0; \frac{\partial E_c(\Pi(t))}{\partial m_c(t)} > 0.$$

Equilibrium collaborations would exhibit the same pattern as in Case 1, with two differences. First, the reason for collaborations being size 2 is now purely because of the desire to maximize the absolute average reputation of a collaboration. Second, the size of the reputation building for each collaboration may differ from Case 1 since external funding is per research unit rather than per collaboration. On this matter the model is silent. However, qualitatively the collaboration pattern at a point in time and over time remains the same.

7.3. Case 3

The measure of collaboration rank is the variance of collaboration reputation; external funding is determined per collaboration; external funding per collaboration is based on the absolute measure:

$$m_c(t) = var(r_n(t), n \in N_c(t)); \frac{\partial E_c(\Pi(t))}{\partial N_c(t)} = 0; \frac{\partial E_c(\Pi(t))}{\partial m_c(t)} > 0.$$

Equilibrium collaborations will again be of size 2 in order to maximize the average reputation and to minimize the division of the collaboration-wide external funding. Because external funding is based on the absolute measure of the variance in reputation, equilibrium collaboration formation will be unique. Collaborations that form in equilibrium will maximize the variance of research unit reputation of the research units that remain in the game at the stage of proposal. If others were to be added to the proposed collaboration, variance would decrease. The exact collaboration compositions may change over time, since the variance within collaborations may lead to churning, or leap-frogging, on the lower half of the reputation distribution. However, the structure of collaborations will remain unchanged.

The average reputation across all research units will be increasing over time. This average will be increasing more quickly than in Cases 1 and 2 if $\frac{\partial r(E_c(t))}{\partial E_c(\Pi(t))} \frac{\partial E_c(\Pi(t))}{\partial m_c(t)}$ is decreasing in $m_c(t)$. Empirical evidence from Arora, David and Gambardella [1] indicates that the effect of reputation level, what they call knowledge, on the change in reputation level, which they call research output, exhibits diminishing returns[25].

The variance, however, will be increasing if the initial distribution of reputations is uniform as well as under more general conditions. The increasing variance conditions are derived next.

The collaboration formation pattern is size 2, with collaborations forming in order of distance between reputation levels. The variance of the reputation level distribution is shown to be increasing between any two periods for the general case of $\frac{k}{2}$ collaborations (k research unit). The variance is increasing if the following expression holds:

$$\sum_{i=1}^{k} \left(X_i - \bar{X}\right)^2 < \sum_{i=1}^{k} \left(X_i + Y_i - \bar{X} - \bar{Y}\right)^2$$

where X_i is the original reputation of research unit i, Y_i is the reputation building of research unit i as a result of participating in a collaboration, and $\bar{X}$ and $\bar{Y}$ are the corresponding averages across all research units. The expression reduces to:

$$0 < \sum_{i=1}^{k} \left(Y_i - \bar{Y}\right)^2 + 2\sum_{i=1}^{k} \left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right). \tag{7.1}$$

The first term on the right hand side is positive. The second term on the right hand side may be negative. It will be negative if the distances between the mean and the lower half of the reputation levels is large relative to the distances between the mean and the upper half of the reputation levels for those reputation levels near the extreme. That is, $\left|X_i - \bar{X}\right| |_{X_i<\bar{X},\, Y_i>\bar{Y}}$ is large relative to $\left|X_i - \bar{X}\right| |_{X_i>\bar{X},\, Y_i>\bar{Y}}$

[25] Arora, David and Gambardella [1] also measure an effect of reputation on reputation building via the effect of collaboration size. They find this effect to be positive and exhibiting decreasing returns.

The effect of size on collaboration formation in the theoretical model here can be considered by the comparison between external funding determined per collaboration and determined per research unit.

The direct effect of reputation on reputation-building in Arora, David, and Gambardella is via a technology production function. The collaboration formation model presented here does not consider such a model explicitly, in order to focus on how the presence of external funding affects collaboration formation. This effect alone also exhibits diminishing returns, although of a higher order.

Arora, David, and Gambardella estimate that the sum ofindirect effects of reputation on reputation building yields increasing returns, although of a magnitude of 1.3.

. Also, it will be negative if the converse is true for those reputation levels near the average $\bar{X}$. That is, it will be negative if $\left|X_i - \bar{X}\right| |_{X_i > \bar{X},\ Y_i < \bar{Y}}$ is large relative to $\left|X_i - \bar{X}\right| |_{X_i < \bar{X},\ Y_i < \bar{Y}}$.

The first term of (7.1) may be small relative to the second term if the distribution of reputation building has a smaller mean and/or variance than the distribution of reputation levels. Therefore, in the case where the first term of (7.1) is small relative to the second and the distribution of reputation levels is such that the second term is negative, then the reputation level variance can be decreasing. Otherwise, the variance will be increasing. If the distribution of reputation levels is uniform, then the second term on the right hand side is zero, and so in this case the variance will be increasing.

7.4. Case 4

The measure of collaboration rank is the variance of collaboration reputation; external funding is determined per research unit; external funding per collaboration is based on the absolute measure:

$$m_c(t) = var(r_n(t), n \in N_c(t)); \frac{\partial E_c(\Pi(t))}{\partial N_c(t)} > 0; \frac{\partial E_c(\Pi(t))}{\partial m_c(t)} > 0.$$

Equilibrium collaborations would exhibit the same pattern as in Case 3, with two differences. First, the reason for collaborations being size 2 is now purely because of the desire to maximize the absolute variance in reputation of a collaboration. Second, the size of the reputation building for each collaboration may differ from Case 1 since external funding is per research unit rather than per collaboration. Again, on this matter the model is silent. However, the collaboration pattern at a point in time and over time is not affected.

7.5. Case 5

The measure of collaboration rank is the average collaboration reputation; external funding is determined per collaboration; external funding per collaboration is based on the relative measure:

$$m_c(t) = \bar{r}_c(t); \frac{\partial E_c(\Pi(t))}{\partial N_c(t)} = 0; \frac{\partial E_c(\Pi(t))}{\partial w(m_c(t); m_k(t)\, k = 1, ..., C)} > 0.$$

Equilibrium collaborations will all be of size 2 since funding is given to the entire collaboration and assumed to be split equally between them. Collaborations of size 2 which form in descending order of reputation is an equilibrium formation. If the level of reputation building is in the same order as the initial reputation level, this equilibrium may continue in future periods indefinitely, exactly as in Case 1. The variance of the distribution of reputation across all research units would therefore be increasing over time, as in Case 1.

However, because external funding depends only on rank, other equilibria exist. For instance, if the research unit with the highest reputation can choose to collaborate with the second or third highest-reputation research unit and still attain the highest collaboration rank, then either collaboration will be part of a possible equilibrium.

Because of the multiplicity of equilibria, it is not possible to specify exactly how the distribution of reputation will evolve. Although the average reputation will be increasing, the variance of reputations may not be. These same issues arise in Case 6, and the issues are discussed in greater detail under Case 6.

7.6. Case 6

The measure of collaboration rank is the average collaboration reputation; external funding is determined per research unit; external funding per collaboration is based on the relative measure:

$$m_c(t) = \bar{r}_c(t);\, \frac{\partial E_c(\Pi(t))}{\partial N_c(t)} > 0;\, \frac{\partial E_c(\Pi(t))}{\partial w(m_c(t);m_k(t)\, k=1,...,C)} > 0.$$

Equilibrium collaborations can be of any size from 2 to N. The highest reputation research unit will choose a collaboration so that it knows it will be first ranked. Therefore, a collaboration structure that is ordered in initial reputation level is a possible equilibrium. The highest-reputation research unit is indifferent about the size of the collaboration since its external funding will be fixed by the collaboration's rank. The absolute measure of average reputation is of no concern. If the highest reputation research unit proposes a collaboration of size less than N that will be first ranked, all potential members will accept such a proposal by the same logic. Once that collaboration is formed, the research unit with the highest reputation of those left over will choose a proposal according to the same logic as the original proposer did.

In the initial uniform reputation distribution case considered here, these collaborations will again form, roughly speaking, in order of reputation. However, it will be possible that collaborations are proposed and accepted that do not run exactly in order. The proposer may be indifferent between a collaboration that includes, for instance, the first through fourth ranked research units inclusive and a collaboration that includes the first, second, and fourth ranked research units only. As long as the rank of the collaboration will be unchanged, that is all the proposer and the potential members will care about. This indifference is the reason for multiplicity of equilibria.

Because of the multiplicity of equilibria, it is not possible to specify exactly how the distribution of reputation will evolve. In the case where collaborations do run in order of the current reputation level, then the ordering will remain the same. It is only in the case where collaborations form that "skip over" some research unit(s) where churning, or leapfrogging, in the reputation distribution is possible. The exact degree of churning depends on the particular distribution of reputation.

The larger is reputation building relative to the reputation level, the larger the degree of churning that will be expected. However, since the proposers will be indifferent between having ordered collaborations or not (of the same rank), there is no reason to expect this type of churning to be prevalent.

If there is more than one collaboration that is formed in order of reputation level, then the average reputation level will be increasing, but the variance of reputation levels will be also. If there is a grand collaboration of size N, then the average will be increasing at a higher rate than when there is more than one collaboration. This follows from the fact that every research unit is in the first ranked collaboration if there is a grand collaboration, but if there is more than one collaboration, then some research units will have lower reputation building. The maximum reputation level will be unaffected by this difference as long as the highest reputation level research unit is always in the highest ranked collaboration, as it will be in equilibrium.

If there is some degree of skipping in collaboration formation, resulting in churning, then the variance may still be increasing. The logic for why this is the case is very similar to that for describing when the variance is increasing in Case 3, as set out in the appendix. In the case of a uniform distribution of reputation levels, the variance will be increasing.

7.7. Case 7

The measure of collaboration rank is the variance of collaboration reputation; external funding is determined per collaboration; external funding per collaboration is based on the relative measure:

$$m_c(t) = var\left(r_n(t), n \in N_c(t)\right); \frac{\partial E_c(\Pi(t))}{\partial N_c(t)} = 0; \frac{\partial E_c(\Pi(t))}{\partial w(m_c(t); m_k(t)\, k = 1, ..., C)} > 0.$$

Equilibrium collaborations will be of size 2 due to the division of external funding between collaboration members. Collaborations will be proposed and accepted to maximize the potential ranking of variance. The variance will decrease if a third research unit is added with a reputation between that of the first two, and is straightforward to prove.

There is, however, multiplicity of equilibria, even for an initially uniform distribution. Only the relative ranking of collaboration variance matters for the level of external funding, so a proposed collaboration may be less than the maximum possible variance as long as the collaboration will retain its first ranking among the remaining available potential collaborations.

Churning is possible due to the variance measure to determine external funding. The degree of churning will depend on the returns of external funding on reputation building. If the returns are decreasing, then there will simply be cycling of reputation ranking among the lower reputation research units, with no one breaking through into the upper ranks. However, if the marginal effect is sufficiently increasing, then it would be possible for initially low reputation research units to become relatively high reputation research units, at least temporarily. The one research unit whose ranking will never change in equilibrium is the highest ranking research unit. The returns to reputation building of research funding will determine the proportion of research units, from lowest to highest, that will experience a change in rank as a result of collaborations.

The average reputation level of all research units will be increasing over time. Exactly which collaborations of size 2 are chosen will not affect this average. As shown for Case 3, the variance may be increasing, by similar logic. The variance will increase starting from an initially uniform distribution.

7.8. Case 8

The measure of collaboration rank is the variance of collaboration reputation; external funding is determined per research unit; external funding per collaboration is based on the relative measure:

$$m_c(t) = var\left(r_n(t), n \in N_c(t)\right); \frac{\partial E_c(\Pi(t))}{\partial N_c(t)} > 0; \frac{\partial E_c(\Pi(t))}{\partial w(m_c(t); m_k(t)\, k = 1, ..., C)} > 0.$$

Equilibrium collaborations are of size 2 and size N in this setting since only the rank matters for external funding, and funding is per research unit. In either case, the potential members of the coalition can be assured of being ranked as relatively high as possible. Equilibrium collaborations of size between 2 and N are also possible, but only if the resulting decrease in variance will not decrease the proposed collaboration's ranking relative to the ranking without more than two members. From an initially uniform distribution, this increase in size without a decrease in ranking is easily achieved by increasing membership in order from the extreme levels of reputation and working inward toward the median. The initial proposer and potential members will be indifferent between all of these collaborations, and thus each of the collaborations that decrease variance without decreasing rank are possible equilibria.

Equilibrium collaborations that are not ordered by reputation level distance between members is also possible, as in Cases 6 and 7. This is an additional potential source of churning.

In the case of a grand collaboration of size N, reputation building will be equal across research units, although the reputation distribution will remain of the same variance as the average increases. In the case of size 2 collaborations, then churning is possible as in Case 6 described above. The increase in average reputation will be smaller with more collaborations than with fewer. Again, the variance may be non-decreasing. If there is one grand collaboration, the variance will be constant. If there is more than one collaboration with an initially uniform reputation distribution, then variance will be increasing.

In general, the intuition for variance to be non-decreasing in a wide variety of cases is that for the variance to be decreasing, the lower reputation research units would have to be building reputation levels faster than the others. There is no guaranteed mechanism for such catching-up here since reputation-building occurs by collaboration members together. However, collaborations can lessen or eliminate the increase in variance that might have otherwise occurred. The grand collaboration is an illustrative example. Clearly, the collaborations serve to increase the overall average of reputation, or technological capability, of the research units through the external funding.

8. Appendix: Outcomes for Reputation Distribution of Interactions between National and Supra-National Funding Regimes.

(For mixed funding regime 1.A.i, see text, section 4.1.)

1. The national agency funds independently of the supra-national agency decision

A. The national agency funds all research units in the nation to produce an equal change in reputation

ii. The supra-national agency funds the k highest reputation variance collaborations

This case is depicted in Figure 2. The new average for each nation and overall is higher, with the expressions the same as those for case 1Ai. The new variance for nation 2 is the same as for case 1Ai. The new variance for nation 1 may decrease. The third term of Var_{1A}, $\frac{2\sum_1^{N_1}(r_n-\bar{r}_1)(\Delta r_n-\Delta\bar{r}_1)}{N_1}$, will be negative. A sufficient condition for Var_{1A} to decrease is $\left|\frac{2\sum_1^{N_1}(r_n-\bar{r}_1)(\Delta r_n-\Delta\bar{r}_1)}{N_1}\right| > \frac{\sum_1^{N_1}(\Delta r_n-\Delta\bar{r}_1)^2}{N_1}$, which holds for $(r_n - \bar{r}_1) > (\Delta r_n - \Delta \bar{r}_1)\ \forall n \in [1, ..., N_1]$. That is, the change in reputation is small relative to the level.

Overall variance is unambiguously increasing, as the third term on the right-hand side is equal to zero. This increase in variance will therefore be smaller than that of case 1Ai.

1. The national agency funds independently of the supra-national agency decision

B. The national agency funds half of all research units in the nation, funding the top half

i. The supra-national agency funds the k highest average reputation collaborations

This case is depicted in Figure 3. The new average for each nation and overall is higher. The averages are:

$$\bar{r}_{1A} = \frac{\sum_1^{N_1} r_n}{N_1} + \frac{\left[\frac{N_1}{2}v + \left(\frac{N_1}{2} - k\right)\Delta r_L + k\left(\Delta r_H + \Delta r_L\right)\right]}{N_1};$$

$$\bar{r}_{2A} = \frac{\sum_1^{N_2} r_n}{N_2} + \frac{\left[\frac{N_2}{2}v + \left(\frac{N_2}{2} - k\right)\Delta r_L + k\left(\Delta r_H + \Delta r_L\right)\right]}{N_2};$$

the new overall average is

$$\bar{r}_{A} = \frac{\sum_1^{N} r_n}{N} + \frac{\left[\frac{N}{2}v + \left(\frac{N}{2} - 2k\right)\Delta r_L + 2k\left(\Delta r_H + \Delta r_L\right)\right]}{N}.$$

These changes in average are smaller than those in cases 1A i and ii.

The new variances for each nation and overall unambiguously increase, as can be easily shown. Relative to the change in variances for case 1Ai, it is not analytically conclusive which case's variances will rise more.

1. The national agency funds independently of the supra-national agency decision

B. The national agency funds half of all research units in the nation, funding the top half

ii. The supra-national agency funds the k highest reputation variance collaborations

This case is depicted in Figure 4. The new national averages are:

$$\bar{r}_{1A} = \frac{\sum_1^{N_1} r_n}{N_1} + \frac{\left[\left(\frac{N_1}{2} - k\right)v + \frac{N_1}{2}\Delta r_L + k\Delta r_H\right]}{N_1};$$

$$\bar{r}_{2A} = \frac{\sum_1^{N_2} r_n}{N_2} + \frac{\left[\frac{N_2}{2}v + \left(\frac{N_2}{2} - k\right)\Delta r_L + k\left(\Delta r_H + \Delta r_L\right)\right]}{N_2};$$

the new overall average is

$$\bar{r}_A = \frac{\sum_1^N r_n}{N} + \frac{\left[\left(\frac{N}{2} - k\right)v + \left(\frac{N}{2}\right)\Delta r_L + 2k\Delta r_H\right]}{N}.$$

The average in nation 1 will be smaller than that of case 1Bi; the average of nation 2 will be the same, and thus the overall average is slightly smaller than case 1Bi as well.

The new variance for nation 2 will be the same as for case 1Bi. The new variance for nation 1 may fall from the old variance[26], and will thus be smaller than the variance in case 1Bi. The overall variance will rise for k sufficiently small.

1. The national agency funds independently of the supra-national agency decision

C. The national agency funds half of all research units in the nation, funding the bottom half

i. The supra-national agency funds the k highest average reputation collaborations

This case is depicted in Figure 5. The new averages are:

$$\bar{r}_{1A} = \frac{\sum_1^{N_1} r_n}{N_1} + \frac{\left[\left(\frac{N_1}{2} - k\right)v + \frac{N_1}{2}\Delta r_L + k\Delta r_H\right]}{N_1};$$

$$\bar{r}_{2A} = \frac{\sum_1^{N_2} r_n}{N_2} + \frac{\left[\left(\frac{N_2}{2} - k\right)v + \frac{N_2}{2}\Delta r_L + k\Delta r_H\right]}{N_2};$$

the new overall average is

$$\bar{r}_A = \frac{\sum_1^N r_n}{N} + \frac{\left[\left(\frac{N}{2} - 2k\right)v + \frac{N}{2}\Delta r_L + 2k\Delta r_H\right]}{N}.$$

The new average for nation 1 is the same as for case 1Bii. The new averages are thus all smaller than those of case 1Bi, and cases 1Ai and 1Aii.

[26] The variance for region 1 and overall may fall for k sufficiently large.

The variances for both nations and overall can easily be shown to decrease for k sufficiently small, and for the level of reputations r_n sufficiently large relative to the changes in reputation Δr_n. This is the first case considered where both nation's variances can go down.

1. The national agency funds independently of the supra-national agency decision

C. The national agency funds half of all research units in the nation, funding the bottom half

ii. The supra-national agency funds the k highest reputation variance collaborations

This case is depicted as Figure 6. The new averages are:

$$\bar{r}_{1A} = \frac{\sum_1^{N_1} r_n}{N_1} + \frac{\left[\left(\frac{N_1}{2} - k\right)\Delta r_L + \frac{N_1}{2}v + k\left(\Delta r_H + \Delta r_L\right)\right]}{N_1};$$

$$\bar{r}_{2A} = \frac{\sum_1^{N_2} r_n}{N_2} + \frac{\left[\left(\frac{N_2}{2} - k\right)v + \frac{N_2}{2}\Delta r_L + k\left(\Delta r_H\right)\right]}{N_2};$$

the new overall average is

$$\bar{r}_A = \frac{\sum_1^{N} r_n}{N} + \frac{\left[\left(\frac{N}{2} - k\right)v + \frac{N}{2}\Delta r_L + 2k\Delta r_H\right]}{N}.$$

The new average in nation 1 is the same as in case 1Bi. The average in nation 2 is the same as in case 1Ci. The overall average is therefore larger than in case 1Ci, and is equal to that of case 1Bii.

The new variance for nation 2 is the same as in case 1Ci. The new variance for nation 1 is easily seen to be unambiguously smaller than the variance in case 1Ci. The new overall variance can be shown to be smaller than the new overall variance in case 1Ci, and smaller than the original variance under similar conditions as those for case 1Ci.

2. The national agency funds those research units not funded by the supra-national agency

i. The supra-national agency funds the k highest average reputation collaborations

This case is illustrated in Figure 7. The new averages will be:

$$\bar{r}_{1A} = \frac{\sum_1^{N_1} r_n}{N_1} + \frac{\left[\left(N_1 - k\right)\Delta r_L + k\Delta r_H\right]}{N_1};$$

$$\bar{r}_{2A} = \frac{\sum_1^{N_2} r_n}{N_2} + \frac{[N_2 \Delta r_L + k \Delta r_H]}{N_2};$$

the new overall average is

$$\bar{r}_A = \frac{\sum_1^{N} r_n}{N} + \frac{[(N-2k)\,\Delta r_L + 2k \Delta r_H]}{N}.$$

These new averages are unambiguously smaller than those averages of case 1Ai, and unambiguously larger than those averages of case 1Ci. They will also be larger than the new averages of case 1Bi for k small enough and Δr_L sufficiently larger than v.

It is straightforward to show that the variance will unambiguously rise in each nation and overall.

2. The national agency funds those research units not funded by the supra-national agency

ii. The supra-national agency funds the k highest reputation variance collaborations

This case is depicted in Figure 8. The new averages are the same as those of case 2i. The new variance for nation 2 is the same as for case 2i. The new variance for nation 1 may decrease. It is not possible to analytically determine whether the new nation 1 variance will be larger or smaller than that of case 1Cii, the case with the smallest nation 1 new variance thus far. Overall variance will unambiguously increase.

3. The national agency funds only those research units funded by the supra-national agency

i. The supra-national agency funds the k highest average reputation collaborations

This case is illustrated in Figure 9. The new averages will be:

$$\bar{r}_{1A} = \frac{\sum_1^{N_1} r_n}{N_1} + \frac{[(N_1 - k)\,v + k\,(\Delta r_H + \Delta r_L)]}{N_1};$$

$$\bar{r}_{2A} = \frac{\sum_1^{N_2} r_n}{N_2} + \frac{[(N_2 - k)\,v + k\,(\Delta r_H + \Delta r_L)]}{N_2};$$

the new overall average is

$$\bar{r}_A = \frac{\sum_1^N r_n}{N} + \frac{[(N-2k)\,v + 2k\,(\Delta r_H + \Delta r_L)]}{N}.$$

These new averages will be smaller than those of case 2i unless k is sufficiently large and $(\Delta r_L - v)$ is sufficiently small. They are unambiguously smaller than case 1Bi and 1Ci.

It is straightforward to show that variance will increase in each nation and overall. The increase in variance will be larger than that of case 2i.

3. The national agency funds only those research units funded by the supra-national agency

ii. The supra-national agency funds the k highest reputation variance collaborations

This case is depicted in Figure 10. The new averages will be the same as in case 3i. The new variance for nation 2 is the same as for case 2i. The new variance for nation 1 may decrease. It is not possible to analytically determine whether new nation 1 variance will be larger or smaller than that of case 1Cii. Overall variance will increase unambiguously.

	Maximize Average		**Maximize Variance**	
Per Collaboration	**Absolute**	Case 1	**Absolute**	Case 3
	Relative	Case 5	**Relative**	Case 7
Per Research Unit	**Absolute**	Case 2	**Absolute**	Case 4
	Relative	Case 6	**Relative**	Case 8

Table 1: Section 2 Summary of Cases

	Average		**Variance**	
Per Collaboration	**1.Absolute**	Size 2; unique; variance increasing	**3.Absolute**	Size 2; unique; variance increasing under uniform distribution
	5.Relative	Size 2; multiplicity; leapfrogging possible	**7.Relative**	Size 2; multiplicity; leapfrogging possible
Per Research Unit	**2.Absolute**	Size 2; unique; variance increasing	**4.Absolute**	Size 2; unique, variance increasing under uniform distribution
	6.Relative	Size 2 toN; multiplicity; leapfrogging possible	**8. Relative**	Size 2 to N; multiplicity; leapfrogging possible

Table 2: Section 2 Summary of Results

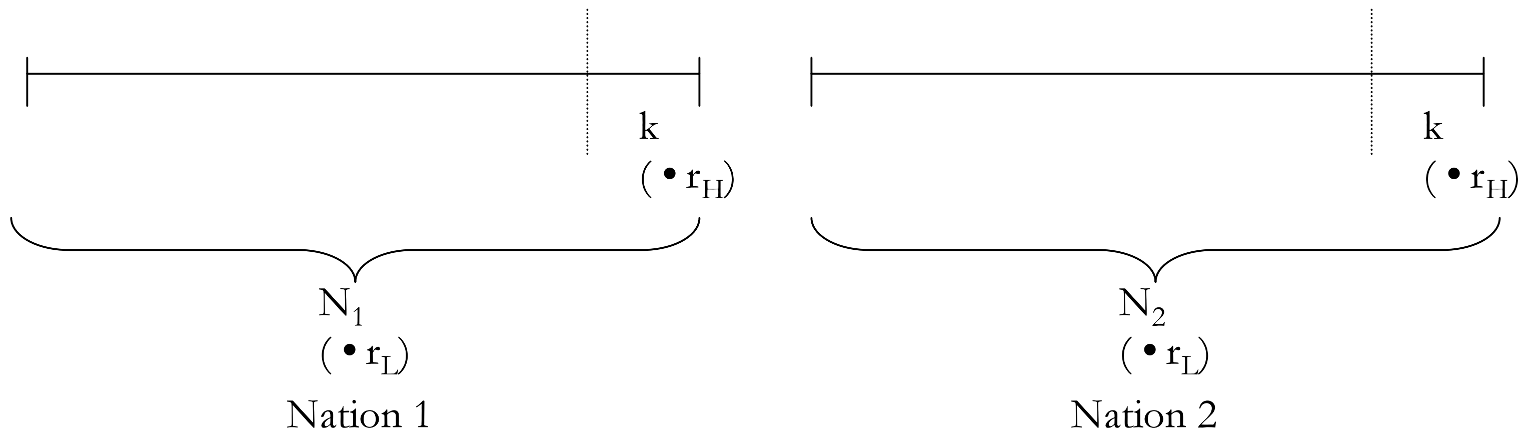

Figure 1: Case 1Ai

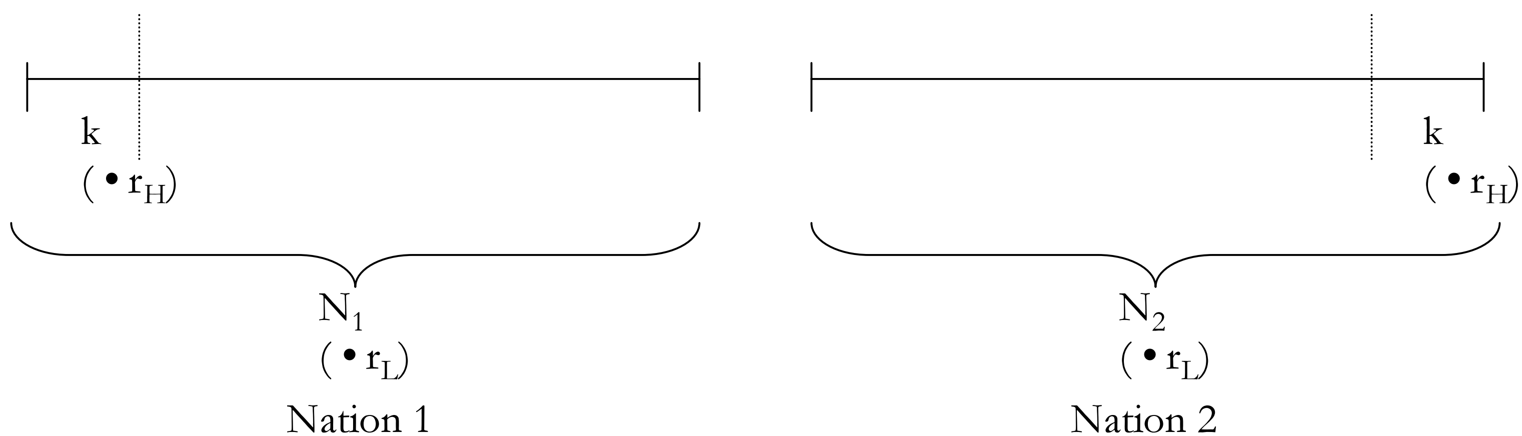

Figure 2: Case 1Aii

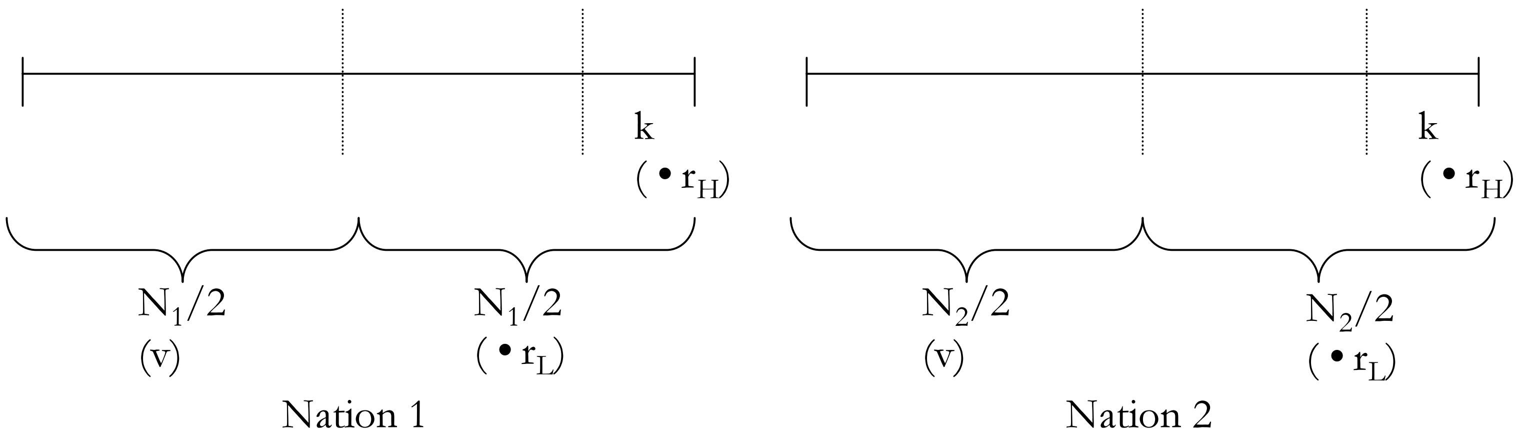

Figure 3: Case 1Bi

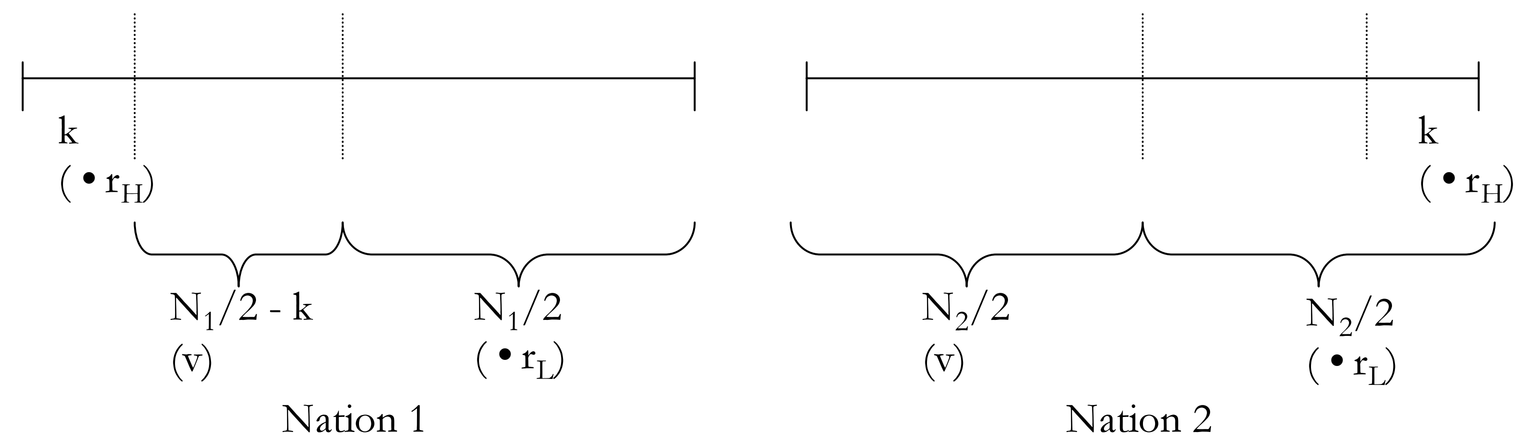

Figure 4: Case 1Bii

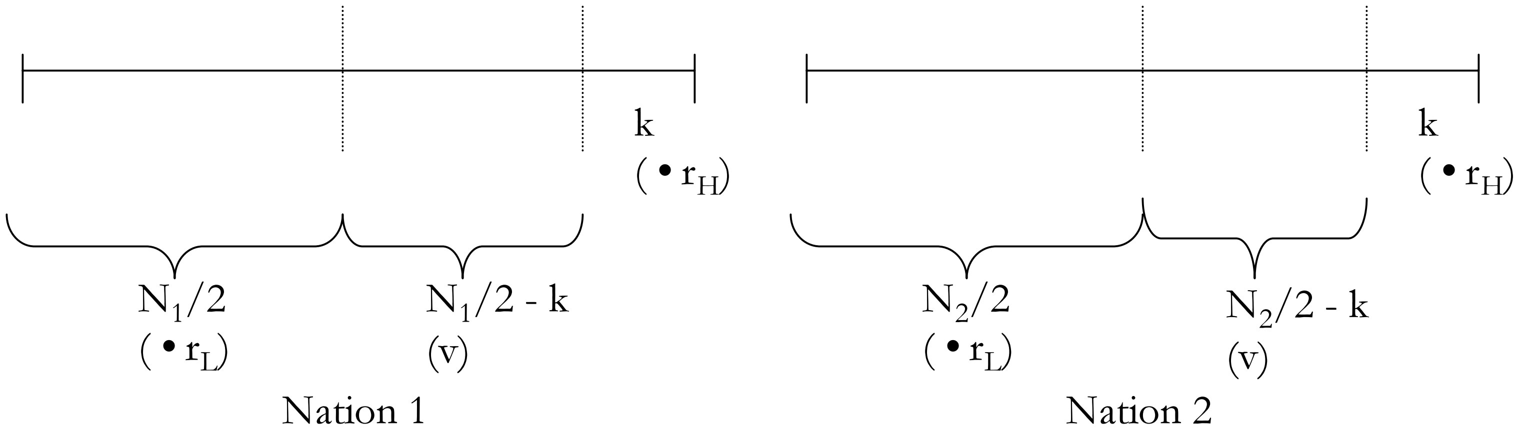

Figure 5: Case 1Ci

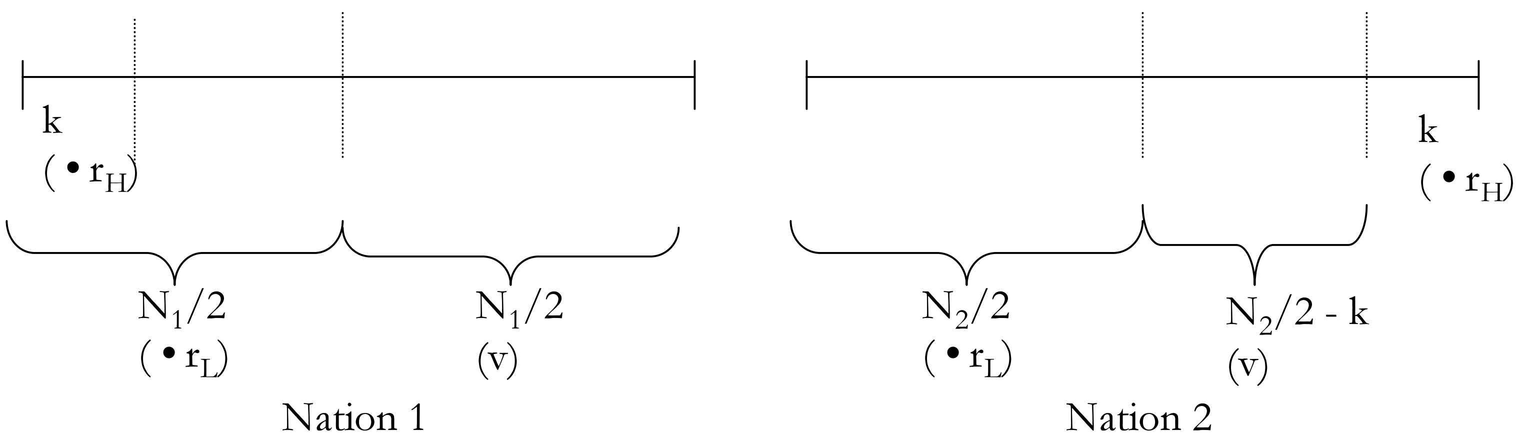

Figure 6: Case 1Cii

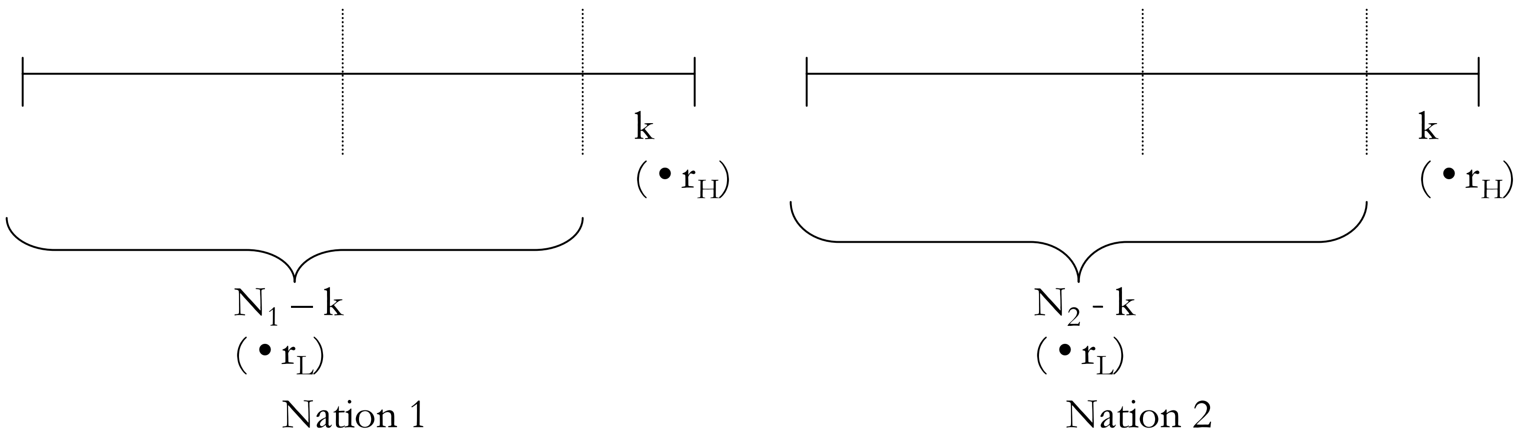

Figure 7: Case 2i

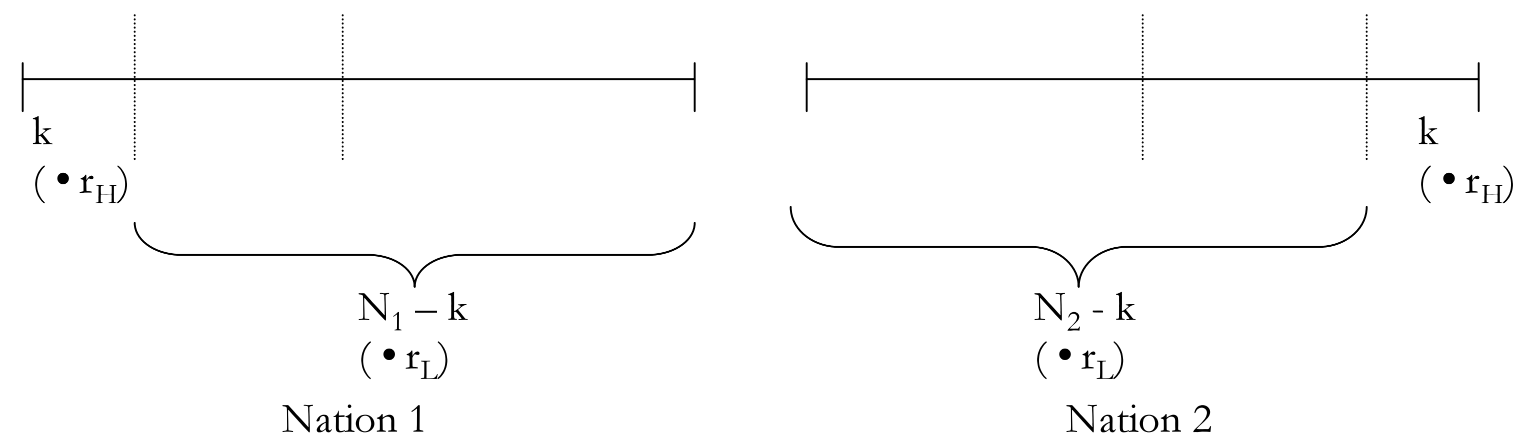

Figure 8: Case 2ii

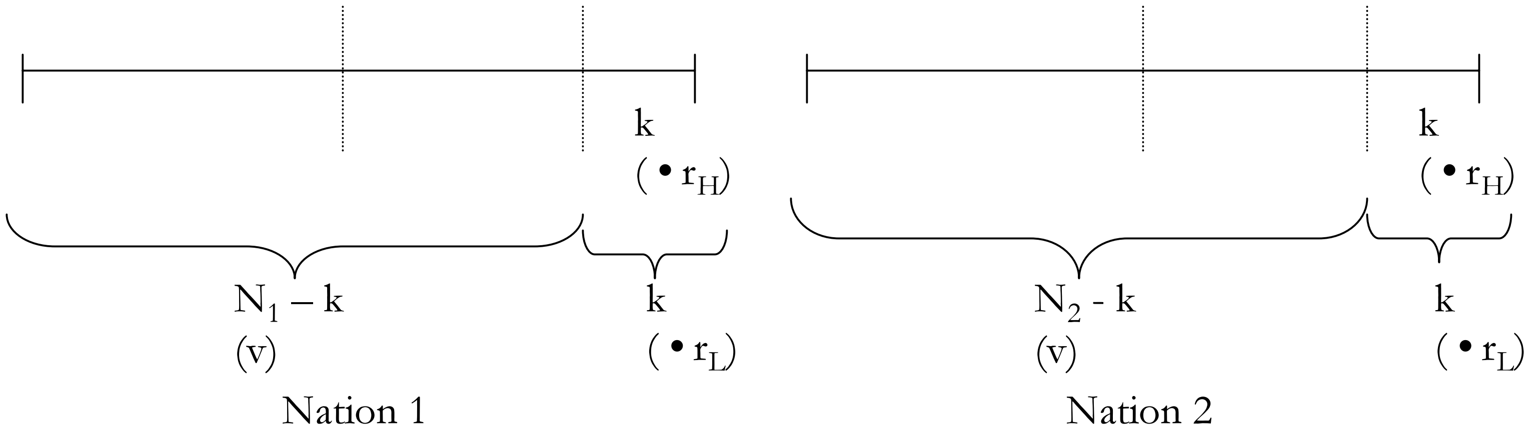

Figure 9: Case 3i

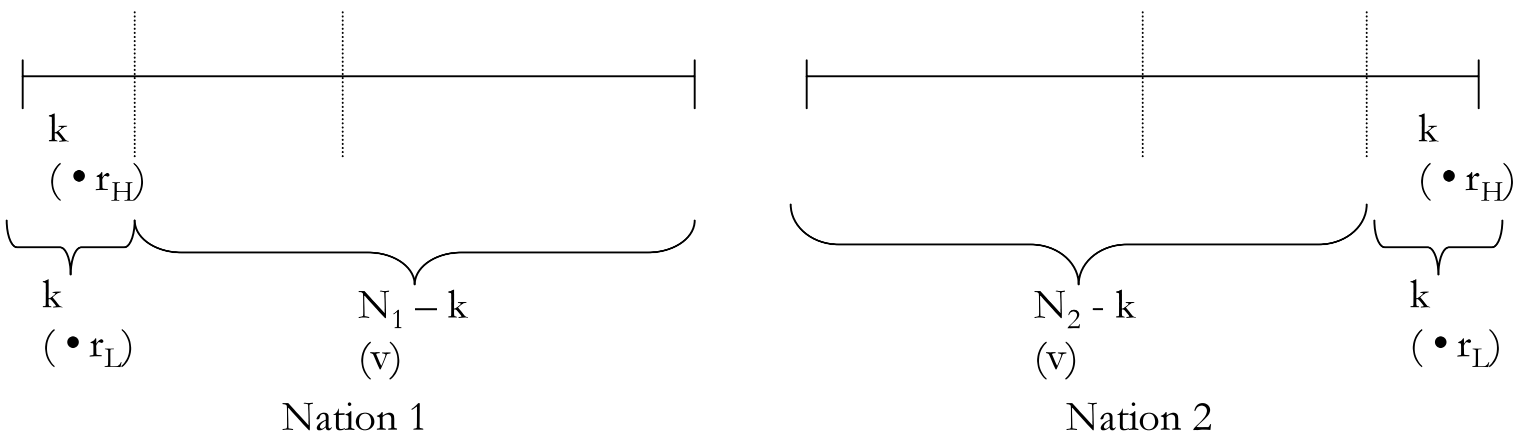

Figure 10: Case 3ii

		AFTER									
		Rules									
	BEFORE	1Ai	1Aii	1Bi	1Bii	1Ci	1Cii	2i	2ii	3i	3ii
Average region 1	99.50	106.00	106.00	104.50	104.20	104.20	104.50	105.25	105.25	103.45	103.45
Variance region 1	841.67	983.33	725.76	1065.91	821.27	875.82	656.82	909.28	780.49	1030.86	696.01
Var/avg region 1	8.46	9.28	6.85	10.20	7.88	8.41	6.29	8.64	7.42	9.96	6.73
Var/avgsqd region 1	0.09	0.09	0.06	0.10	0.08	0.08	0.06	0.08	0.07	0.10	0.07
Average region 2	199.50	206.00	206.00	204.50	204.50	204.20	204.20	205.25	205.25	203.45	203.45
Variance region 2	841.67	983.33	983.33	1065.91	1065.91	875.82	875.82	909.28	909.28	1030.86	1030.86
Var/avg region 2	4.22	4.77	4.77	5.21	5.21	4.29	4.29	4.43	4.43	5.07	5.07
Var/avgsqd region 2	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Average overall	149.50	156.00	156.00	154.50	154.35	154.20	154.35	155.25	155.25	153.45	153.45
Variance overall	3350.00	3490.95	3362.81	3573.12	3466.51	3383.98	3259.98	3417.27	3353.20	3538.24	3371.66
Var/avg overall	22.41	22.38	21.56	23.13	22.46	21.95	21.12	22.01	21.60	23.06	21.97
Var/avgsqd overall	0.15	0.14	0.14	0.15	0.15	0.14	0.14	0.14	0.14	0.15	0.14

Table 3: Example Summary

AVERAGE AFTER: Overall		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	156.00	156.00
	Fund top half	154.50	154.35
	Fund bottom half	154.20	154.35
Fund those not funded supranationally		155.25	155.25
Fund only those funded supranationally		153.45	153.45

AVERAGE AFTER: Region 1		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	106.00	106.00
	Fund top half	104.50	104.20
	Fund bottom half	104.20	104.50
Fund those not funded supranationally		105.25	105.25
Fund only those funded supranationally		103.45	103.45

AVERAGE AFTER: Region 2		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	206.00	206.00
	Fund top half	204.50	204.50
	Fund bottom half	204.20	204.20
Fund those not funded supranationally		205.25	205.25
Fund only those funded supranationally		203.45	203.45

Table 4A: Comparison of Average Reputations across Funding Regimes

VARIANCE AFTER: Overall		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	3490.95	3362.81
	Fund top half	3573.12	3466.51
	Fund bottom half	3383.98	3259.98
Fund those not funded supranationally		3417.27	3353.20
Fund only those funded supranationally		3538.24	3371.66

VARIANCE AFTER: Region 1		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	983.33	725.76
	Fund top half	1065.91	821.27
	Fund bottom half	875.82	656.82
Fund those not funded supranationally		909.28	780.49
Fund only those funded supranationally		1030.86	696.01

VARIANCE AFTER: Region 2		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	983.33	983.33
	Fund top half	1065.91	1065.91
	Fund bottom half	875.82	875.82
Fund those not funded supranationally		909.28	909.28
Fund only those funded supranationally		1030.86	1030.86

Table 4B: Comparison of Reputation Variances across Funding Regimes

VAR/AVG AFTER: Overall		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	22.38	21.56
	Fund top half	23.13	22.46
	Fund bottom half	21.95	21.12
Fund those not funded supranationally		22.01	21.60
Fund only those funded supranationally		23.06	21.97

VAR/AVG AFTER: Region 1		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	9.28	6.85
	Fund top half	10.20	7.88
	Fund bottom half	8.41	6.29
Fund those not funded supranationally		8.64	7.42
Fund only those funded supranationally		9.96	6.73

VAR/AVG AFTER: Region 2		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	4.77	4.77
	Fund top half	5.21	5.21
	Fund bottom half	4.29	4.29
Fund those not funded supranationally		4.43	4.43
Fund only those funded supranationally		5.07	5.07

Table 4C: Comparison of Reputation Variance/Mean across Funding Regimes

AVERAGE AFTER: Overall (LN)		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	4.618	4.631
	Fund top half	4.598	4.607
	Fund bottom half	4.604	4.619
Fund those not funded supranationally		4.613	4.620
Fund only those funded supranationally		4.589	4.606

AVERAGE AFTER: Region 1 (LN)		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	4.618	4.631
	Fund top half	4.598	4.607
	Fund bottom half	4.604	4.619
Fund those not funded supranationally		4.613	4.620
Fund only those funded supranationally		4.589	4.606

AVERAGE AFTER: Region 2 (LN)		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	5.316	5.316
	Fund top half	4.598	4.607
	Fund bottom half	4.604	4.619
Fund those not funded supranationally		4.613	4.620
Fund only those funded supranationally		4.589	4.606

Table 5A: Comparison of Average Natural Log Reputations across Funding Regimes

VARIANCE AFTER: Overall (LN)		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	0.181	0.163
	Fund top half	0.193	0.176
	Fund bottom half	0.179	0.161
Fund those not funded supranationally		0.179	0.170
Fund only those funded supranationally		0.192	0.168

VARIANCE AFTER: Region 1 (LN)		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	0.095	0.067
	Fund top half	0.107	0.081
	Fund bottom half	0.088	0.062
Fund those not funded supranationally		0.091	0.076
Fund only those funded supranationally		0.104	0.067

VARIANCE AFTER: Region 2 (LN)		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	0.023	0.023
	Fund top half	0.026	0.026
	Fund bottom half	0.021	0.021
Fund those not funded supranationally		0.022	0.022
Fund only those funded supranationally		0.025	0.025

Table 5B: Comparison of Natural Log Reputation Variances across Funding Regimes

VAR/AVG AFTER: Overall (LN)		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	0.037	0.033
	Fund top half	0.039	0.036
	Fund bottom half	0.036	0.032
Fund those not funded supranationally		0.036	0.034
Fund only those funded supranationally		0.039	0.034

VAR/AVG AFTER: Region 1 (LN)		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	0.021	0.015
	Fund top half	0.023	0.017
	Fund bottom half	0.019	0.014
Fund those not funded supranationally		0.020	0.016
Fund only those funded supranationally		0.023	0.015

VAR/AVG AFTER: Region 2 (LN)		**Supranational Rules**	
National Rules		Fund k highest average	Fund k highest variance
Fund Independently			
	Fund all	0.0044	0.0044
	Fund top half	0.0048	0.0048
	Fund bottom half	0.0040	0.0040
Fund those not funded supranationally		0.0041	0.0041
Fund only those funded supranationally		0.0047	0.0047

Table 5C: Comparison of Natural Log Reputation Variance/Mean across Funding Regimes