Incentive Issues in R&D Consortia: Insights from Applied Game Theory[1]

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Abstract: This paper sketches how insights from applied game theory can be applied to R&D consortia, using a case study on an international plant breeding consortium. The insights jointly comprise a new "logic of collective action in R&D," which is inspired by Olson's *Logic of Collective Action* but goes beyond it. We analyze R&D consortia as institutions that respond to a variety of incentive problems which are obstacles to realizing the benefits of cooperation that arise due to the public-goods nature of outputs, complementarities of inputs, and economies of scale and scope. Additionally, we sketch a "big-picture" consortium game which abstracts from specific incentive issues.

JEL Classification Codes: B41, D02, H41, O31, O32

Submission statement: Today, March 8, 2007, this manuscript is resubmitted to *Contemporary Economic Policy*. It is not under review elsewhere and will not be submitted to another publication while under review at CEP.

Attachments: Please notice that an attached PowerPoint file contains Figure 1 and an attached Excel file contains Figure 2.

[1] Thanks are due to John Mathews, Phil Pardey, Ahmad Rahman, and Perry Shapiro, to attendants of 2005 conference sessions of the WEAI, AAEA, and ASE, to two anonymous referees, and to seminar participants at the University of Sydney, School of Economics and Political Science, for helpful comments. Additionally, I am grateful to Phil for helping to produce Figure 1, and to Luis Sanint (formerly of FLAR) for some very useful ideas and expert insider insights. The usual disclaimer applies.

1. Introduction

1A. Aims and premise

How can applied game theory help analysts understand R&D consortia? Our basic premise is as follows. We view institutions such as R&D consortia as mechanisms for dealing with incentive problems that are obstacles to realizing the benefits of cooperation. These incentive problems involve strategic interaction. Hence we need game theory to understand them. Yet a full-blown game model that incorporates all relevant incentive issues is not feasible – the mathematics is too complex. Thus we review a series of relevant insights – drawing upon several strands of more rigorous literature on incentive problems – and synthesize these insights into a single narrative or 'logic'. We use a case study of an R&D consortium, the Latin American Fund for Irrigated Rice (Spanish acronym: FLAR), to illustrate how the applied game-theoretic insights fit together and how they are relevant to a real-world institution like FLAR. [2] We introduce our proposed logic and FLAR in the present section.

Our principal aims are (i) to set out this logic step by step, (ii) to persuade the reader of its relevance to R&D consortia, and (iii) to suggest how insights from several strands of applied game theory can be applied to R&D consortia.

In the course of our argument, we introduce several concepts that are building blocks for our logic. These include in particular the notion that complexification should precede simplification (crucial to bridging the gap between applied game theory and real-world institutional analysis); the multidimensionality of subsidies; the coexistence of crowding in and reverse crowding out; a novel concept of leadership;

[2] A companion paper (Binenbaum et al. 2003) focuses on the details of the case study and draws more specific conclusions on agricultural research policy.

and a “big-picture game” (i.e. one that abstracts from specific incentive issues) that is a repeated prisoners’ dilemma with unknown horizon.

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List of Abbreviations

CGIAR	Consultative Group on International Agricultural Research
CIAT	(Spanish acronym) International Center for Tropical Agriculture
FLAR	(Spanish acronym) Latin American Fund for Irrigated Rice
IP	Intellectual Property
IPR	Intellectual Property Rights
PD	Prisoners’ Dilemma
PGR	Plant-Genetic Resources
R&D	Research and Development
RDCs	R&D Corporations (Australia)
WARDA	West African Rice Development Association (also known as Africa Rice Center)

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1B. Approach and overview

Olson (1965) elaborated a key insight from the literature on public goods (e.g. Samuelson 1954, 1955) – namely that the existence of a group of players with a common interest does not automatically give rise to collective action, or may result in collective action at a suboptimal level. At the core of Olson’s *logic* is a simple mathematical model that yields several propositions, e.g. those relating group size to the severity of the collective action problem. The decades since Olson (1965) have witnessed an explosion of applied game-theoretic models of a number of incentive problems that are relevant to collective action. Hence we propose an updated, more conceptual logic that can accommodate much of this subsequent literature and does more justice to the complexity of real-world institutions (Figure 1). We think of participants in an R&D consortium as players in a game, who have certain reasons for joining the consortium (box A in Figure 1) but face incentive issues (box B) that are obstacles to optimal cooperation. We analyze the resulting arrangement as a solution to those incentive issues, emphasizing the role of leadership (box F).

[Figure 1 approximately here]

Who are the players - individuals, or households, or organizations, or governments, etc.? This is a tricky and important question. We take a flexible approach. In the next subsection, we sketch FLAR and argue that its "representative organizations" (one for each country) are the relevant collective-action players. However, a few individuals were instrumental in founding and designing FLAR (see below).

Why should a group of players form an R&D consortium? There are three key technical reasons for doing so (box A).[3] First, R&D outputs are typically (imperfect) public goods: they are characterized by imperfect rivalry and imperfect (or costly) appropriability. This is the reason for collective action that Olson (1965) and the collective-action literature generally focuses on. A second key reason is the existence of complementary or synergistic assets – such as intellectual property, genetic materials, and employees' expertise – that serve as inputs into the R&D process. The third rationale for collective action consists of economies of scale and scope. We discuss each of these rationales in section II. They share the feature of *mutual*

[3] Additional rationales for R&D consortia include mutual learning, risk reduction, duplication avoidance, and network positioning (Binenbaum et al. 2003).

positive externalities. In other words, players' interests in cooperating converge to some extent.

Suppose that, due to some combination of these three key reasons, it is optimal to form an R&D consortium. Incentive problems (box B) – which may be internal or external to the consortium – constitute obstacles to optimal cooperation. The fundamental reason underlying these incentive problems is that players' interests diverge to some extent too. This tension of convergence and divergence of interests is the core theme of the economics-of-contracts literature.[4]

The formal literature on R&D consortia commonly assumes that players are for-profit firms. How, then, to characterize players' objectives in hybrid public-private R&D consortia? While organizations' objectives are typically complex, we believe *own-institution bias* to be a common phenomenon. That is, even non-profit organizations that have pro-social missions will often have their own institutional interests: while they seek to promote their missions, they are keen on receiving the resources and credit for doing so. Thus, if other organizations pursue the same mission, tensions may result.

We aim to do justice to complexity by sketching the full picture of relevant incentive problems (box C). We show in section III – and illustrate using the FLAR case – that many incentive problems are simultaneously relevant. A single game incorporating all these problems would be far too complex to fully model mathematically. Moreover, players are not perfectly rational or self-interested. Thus we need to take into account insights from the social and cognitive sciences that may increase

[4] For a handy summary of this literature, see Salanié (2005).

complexity even further (horizontal arrows above box C). However, social and cognitive factors can also simplify the game (horizontal arrows below box C). For example, players reduce complex games to manageable structures through pattern recognition; moral values limit opportunistic behavior.

We devote section IV to boxes D, E and F. A central tenet of our approach is that complexification should precede simplification. Only after having sketched the issues in their full complexity do we simplify the game to a manageable structure (box D). Due to the core feature of mutual positive externalities, this will typically be a repeated prisoners' dilemma with unknown horizon. In such games, the Folk Theorem applies: various gradations and combinations of non-cooperation and cooperation are incentive-compatible (box E). To narrow down this range to a unique solution - an explanation for the institutional arrangement – one needs to impose equilibrium refinements. We emphasize one particular kind of refinement, interpreting *leadership* as the ability to choose one scenario from the incentive-compatible set. Social and cognitive factors help explain this ability (box F and adjacent boxes).

We conclude by reviewing the paper's main insights (section V).

1C. Sketch of FLAR

Before the mid-1990s, practically all developing-world agricultural R&D was publicly funded.[5] FLAR is among a small number of pioneering attempts to catalyze the local private sector to play a more active role in agricultural R&D (Binenbaum et al. 2003). It was founded in 1995 to conduct a range of activities – primarily plant breeding – related to irrigated rice. Recently, the first FLAR rice varieties were released. Additionally, FLAR has recently become involved in agronomy project. While FLAR is relatively small – its annual de facto budget (which is larger than its formal budget (including in-kind contributions such as facilities and delegates' time and travel, but excluding the agronomy project) is about $1 million – it does illustrate key elements of our proposed logic.

Current and past FLAR member countries are listed in Table 1. Among members, the International Center for Tropical Agriculture (Spanish acronym CIAT) plays a central

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Table 1. FLAR member countries/institutes, April 2006

Current members	Past members
Argentina	Chile
Bolivia	CIRAD †
* Brazil	Cuba
* CIAT †	IRRI †
* Colombia	Paraguay
Costa Rica	
Ecuador	
Guatemala	
Guyana	
Honduras	
Mexico	
Nicaragua	
Panama	
Uruguay	

[5] We are referring here to modern R&D, not to the important, ubiquitous and age-old stream of agricultural innovations by successive generations of farmers. For data on public versus private funding of R&D worldwide, see Pardey & Beintema (2001).

* Venezuela

* Founding members

† CIAT: *Centro Internacional de Agricultura Tropical*
CIRAD: *Centre de Coopération International en Recherche Agronomique pour le Développement*
IRRI: International Rice Research Institute

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role. CIAT is one of the (research) Centers of the Consultative Group on International Agricultural Research (CGIAR). The CGIAR and its Centers are essentially a conduit for development assistance (sponsored by rich countries and private philanthropic foundations) and have played – and are still playing – a big role in the introduction and adaptation of modern agricultural technology to the developing world. CIAT currently is the only non-country FLAR member and hosts FLAR at its headquarters and main research campus near Cali, Colombia.

Two salient features of FLAR affect the proper characterization of its members as players. First, FLAR members vary widely in size, as measured by irrigated rice output (Figure 2). [Figure 2 about here] Their R&D capabilities are similarly asymmetric. Second, an important principle of FLAR is *single representation*: each member country is represented by one organization, called a *representative*. A national government has veto power over which organization will act as its representative, but is only indirectly involved itself. FLAR representatives are closely connected to the rice sector and/or agricultural R&D. The key players in FLAR are not member countries' governments, but their respective representative organizations, whose role derives from domestic dominance in rice production, processing and/or breeding. The representatives' objective is primarily to bolster the productivity and competitiveness of their domestic rice sector, in particular of their members or clients

– rice farmers and/or rice-processing industries. However, there may be additional objectives, namely to reinforce the organization's domestic leadership position and, relatedly, to receive the credit for benefiting their constituents. We have found own-institution bias to play a significant role in FLAR (Binenbaum et al. 2003).

FLAR representatives occupy a wide spectrum along the public-private axis. For example, Cuba's representative – when Cuba was a member – was a 100% public-sector organization, while Costa Rica's representative is a 100% private-sector consortium. Most representatives fall somewhere between these two extremes. Sometimes a public-sector representative is privately funded. Representatives' constituents include governments, rice farmers, seed firms, and rice processing firms. They typically play a latent role: they are mostly not active players, but might become so under certain conditions. We rarely observed this in our case study (Binenbaum et al. 2003).

2. Rationales for collective action

2A. A mixed public goods characterization

To understand an R&D consortium, one needs to properly characterize its outputs. This is not a straightforward exercise – R&D outputs possess in varying degrees the public-goods characteristics of non-rivalry (also known as non-diminishability) and non-excludability. Thus different strands of literature are – sometimes simultaneously – relevant.

When both excludability and rivalry are low, Samuelson's (1954; 1955) model of pure public goods may be appropriate. With low excludability but high rivalry, the common-access-resource literature (which builds on Hardin 1968) is relevant. When excludability is high but rivalry low, a club-goods model (as pioneered by Buchanan 1965) is nearer the mark.

Intellectual property (IP) rights (IPR) confer some excludability. Perfect excludability would require costless and universal IP protection and perfect enforcement. Clearly this is not the case in the real world. Application costs are substantial; the requisite IP expertise is expensive; legal systems are overburdened; enforcement is imperfect and requires costly and time-consuming litigation. All these factors are compounded by the existence of multiple jurisdictions. Many types of R&D output are not patentable in most jurisdictions. For example, Latin American IP systems do not allow patent protection for plant varieties; instead, they use a weaker form of IPR, plant variety protection. On the other hand, a technology's excludability can be strengthened by complementary assets such as tacit knowledge, codified but confidential information, and objects embodying the technology,

R&D outputs may not be completely non-rivalrous either. It is true that one player's possession of knowledge does not diminish the amount of knowledge available to other players. But if the players are competitors in product markets, then one player's possession of information may enable her to capture another player's market share. Clearly, this introduces an aspect of R&D output rivalry into the game. In analyzing the likely (in-)efficiency properties of consortium arrangements, it is important to consider the degree of competition (or rivalry, in public-goods terms) in output markets. This is a key component of R&D consortium models such as Katz (1986). Members' ex ante commitments in the consortium agreement, as well as their level of cooperative behavior once the consortium is in place, depend on it. In Katz (1986), the consortium output vector consists of members' scalar cost parameters of a single product. They then compete in the output market with their reduced cost parameters. Competitors' prospective cost reductions are a disincentive for cooperative behavior of consortium members.

How to characterize FLAR's outputs? FLAR's breeding outputs are excludable to a significant extent. Plant variety protection is reinforced by the need to physically possess the plant genetic resources (PGR) required for breeding. As to non-rivalry, most FLAR members sell their rice output almost exclusively domestically. An important exception to this pattern of insignificance of rice exports of FLAR members is Uruguay, which exports large amounts of rice (worth between US$ 100 and 300 million annually) to Brazil, in direct competition with Brazilian rice producers. This may have had a negative effect on Uruguayan and Brazilian cooperativeness (such as the extent of sharing of plant-genetic resources) within FLAR (Binenbaum et al. 2003).

FLAR's agronomy services are near-pure public goods, generating quick benefits across FLAR member countries and probably spilling over to farmers elsewhere (pers. com. Sanint).

In summary, the FLAR case combines elements of club games, pure public goods, and – to a much lesser extent – common-access resources. Prior to the agronomy project, FLAR clearly came closest to the club model.

2B. Economies of scale and scope

Economies of scale are ubiquitous in modern R&D, particularly because some indivisible infrastructure – a minimum scale – is needed. The significance of scale *economies in a consortium game depends on their range and magnitude relative to each player's size.*

Additionally, joint R&D projects are often, but not always, characterized by economies of scope. Even highly focused projects will often spawn valuable spinoff activities. Economics of scale are, however, a more universal feature and are more suitable for a simple and general mathematical characterization.

The threshold idea can be modeled using a standard U-shaped average curve derived from an R&D production function. Output consists of technological innovations, e.g. increases in a performance variable such as crop yield improvement Y. The minimum infrastructure entails a fixed cost F. Thus there is a threshold effect: for any budget $B < F$, $Y = 0$. Assuming that B is spent efficiently, it is given by the cost function: $C(Y) = B$. The average cost function $C(Y) / Y$ is initially decreasing because it starts at infinity and subsequently F is divided over more and more R&D output units. Additionally, marginal cost $C'(Y)$ is typically initially decreasing as well. Adding critical inputs to the minimum infrastructure will drive average cost down further; specialization ('pin factory') effects occur. Thus the threshold effect is augmented by additional scale effects; the efficient scale $Y^* = \text{argmin } C(Y) / Y$ exceeds the minimum scale $Y^{min} = C^{inv}(F)$. Eventually, as B increases, scale diseconomies due to planning complexity, bureaucratization, and reduced communication of innovative ideas set in. In summary, we expect U-shaped average and marginal cost curves to be characteristic of R&D production processes generally. Olson (1965) takes these same features into account in his model of collective action.

Often, the efficient scale will exceed the investment capacities of separate players, but they can approach or reach it by pooling resources. Due to incentive problems, their investments tend to be suboptimal (as argued below) and may be close to the minimum scale.

FLAR may be not far above its minimum critical mass, but substantially below its efficient size. One indication that overall funding for FLAR is at a suboptimal level is the approximately US$10 million budget of its African counterpart, WARDA (the Africa Rice Center) – an order of magnitude larger than FLAR. WARDA's activities are similar to FLAR's, but it is a traditional CGIAR Center, 100% funded as development assistance. While Latin American national agricultural research systems (NARS) have superior resources compared to their African counterparts – and are thus able to carry out a larger share of R&D activity – this difference is unlikely to fully account for the discrepancy between FLAR and WARDA (Binenbaum et al. 2003).[6]

Initially, economies of scope appeared to be irrelevant to FLAR: it was set up with a strong focus on irrigated-rice breeding (and supporting other players' efforts in this area). However, the success of the agronomy project may have benefited from FLAR's primary focus. Crop performance is central to the success of agricultural systems; thus FLAR – supported by CIAT's agronomic capabilities – may have been particularly well placed to undertake the project. Agronomy may now become a permanent feature of FLAR. FLAR may, on closer inspection, turn out to exhibit economies of scope after all.

2C. Asset complementarities

[6] WARDA serves similar numbers of producers and consumers, but due to organizational and funding constraints an arrangement similar to FLAR may not be feasible for West African rice R&D.

Due to asset complementarities, a grand coalition with full sharing of assets would be optimal. This important stylized feature translates into a simple superadditivity game – the starting point for our discussion of incentive problems.

The collective-action literature has focused on the public-goods and scale-economies rationales for collective action. It has paid less attention has been given to another key reason for collective action: the need to combine complementary (synergistic) assets. The assets may be tacit knowledge, codified information, IPR, or technology-embodying objects such as genetic resources. They comprise inputs and rights to inputs in R&D. The literature on cooperative R&D emphasizes asset complementarities (Hagedoorn et al. 2000) but may have underutilized collective-action concepts. On the other hand, it is important that asset complementarities be incorporated into a collective-action narrative.

Graff et al. (2003) and Heller & Eisenberg (1998) point to the critical problem of combining complementary IP and related assets in the life sciences. Due to genetic combinatorics, genetic resources are a prime example of complementary assets. For this reason, cooperative plant breeding games where each coalition pools its members' PGR tend to satisfy the strict superadditivity property: for any two disjoint coalitions *S* and *S'*, the value of the combination exceeds the sum of the separate values: $V\left(S\cup S'\right)>V\left(S\right)+V\left(S'\right)$. A simple superadditivity game with costless bargaining and transferable value has a unique and Pareto-efficient equilibrium: all PGR owners will join a grand coalition, share their genetic resources for a collective breeding program, and share the resulting benefits according to their respective bargaining positions. This result, while trivial in its own right, is our starting point for analyzing R&D consortia such as FLAR.

This model of coalition formation can be applied to the other collective-action rationales – public goods and economies of scale and scope – as well. We will refer to it as the “baseline model”.

3. Incentive problems

3A. Creation of a Leviathan as a solution to the holdup problem

A variation on the baseline model involving an extreme “hold-up” yields a drastically different result: zero cooperation. Players can mitigate this incentive problem by initially delegating power to another – possibly newly created – player.

In hold-up games players have an incentive to wait to improve their bargaining positions during later negotiation rounds (Cohen 1998; Klein 1998). Suppose that coalitions can grow in successive stages by allowing new members on board. Is it possible for the grand coalition to emerge gradually by having players join one by one, negotiating with those already in the coalition? Suppose that the last player to join has the strongest bargaining position, the next-to-last player the second-strongest, etc. We can construct such a game so as to obtain an impossibility result: even in the presence of superadditivity, there exists no equilibrium with any coalition formation. E.g., there is no PGR sharing whatsoever.

Now consider another model variation. Consider again the extreme hold-up game, but now suppose that, prior to the formation of PGR sharing pools, the players can jointly create another player with the power of Principal and with the objective to maximize joint value and satisfy some sort of fairness criterion (say, Shapley values or the Nash bargaining solution). Of course we will get the (trivial) result that the new player will be created if the cost of doing so is low enough. This may be called the Leviathan result/game, as it is a variation on the theme – developed by Hobbes and subsequent Enlightenment and "contractarian" thinkers – of a social contract whereby players voluntarily delegate power to a government so as to avoid conflict among themselves (Kraus 1998).

We may also construct less extreme versions of hold-up and Leviathan games. Thus, we can construct hold-up games that result in partial coalition formation, and Leviathan games that result in partial delegation of power.

This is one possible rough explanation for the existence of FLAR. Its members agreed to yield to it some of their control over PGR. In fact, the FLAR agreement does not compel members to share all of their genetic resources, but it does provide a mechanism whereby members voluntarily place PGR in the FLAR breeding program.

3B. Coexistence of reverse crowding out and crowding in

We differentiate between crowding in *and* reverse crowding out *and show that these features can coexist even in a univariate (cash) subsidy model. We also point out that they may coexist due to the multivariate nature of subsidies.*

There often exist outside players (i.e. external to the consortium group) willing to subsidize the consortium. The optimal design of such subsidies is not a straightforward exercise – it requires an understanding of the potentially confusing concept of crowding in/out. "Crowding in" and "crowding out" both refer to the effect of public-sector spending on private-sector spending; in the case of crowding in (out), this effect is positive (negative). In other words, the terms mean that public and private expenditures are strategic complements or substitutes, respectively. If a reduction in public expenditure results in increased private expenditure, then we should speak of "reverse crowding out."

Reverse crowding out is of particular interest as it allows benevolent sponsors to reallocate funds to from one worthy cause to another at a reduced opportunity cost. A model of reverse crowding out is easily constructed. An R&D consortium *S*'s value $V(S)$ is a function of – among other things – its budget, which is the sum of its members' contributions: $B = \sum_{k \in S} b_k$. We make the following two 'natural' (in terms of modeling technique) assumptions: $\partial V / \partial B > 0$; $\partial^2 V / \partial B^2 < 0$. Now ignore all other complicating factors and assume the baseline model, with one additional feature: the presence of an exogenous subsidy, which is some fraction of the optimal funding amount $B*$. The budget contributions b_k are the Nash bargaining solution. Now consider a simple comparative statics exercise. Suppose that the subsidy is exogenously reduced, then under the assumptions made, all b_k will increase. This is a "reverse crowding out" result.

The trouble with this model is that it assumes marginal *dis*economies of scale ($\partial^2 V / \partial B^2 < 0$). Here we run into a fundamental problem of neoclassical economics, namely its reliance on convex technology sets. Under the opposite assumption of marginal economies of scale ($\partial^2 V / \partial B^2 > 0$) – which as implied above is more appropriate – it is far more difficult to obtain a general result, but reverse crowding out is still possible.

Matching funding arrangements are characteristic of some consortia, such as the Australian Research and Development Corporations (RDCs) (Alston et al. 1999, 2004). In such arrangements, the subsidy is a function of member contributions. Suppose that the subsidy rate *s* is constrained to be a fixed proportion (which can assume any nonnegative value) of member contributions and is announced in advance. Then member contributions are a (response) function of *s* which will usually feature positive (crowding in) as well as negative (crowding out) sections for different intervals of *s*. This is one way in which crowding in and crowding out can coexist in a single game.

Furthermore, outside support can be multivariate. For instance, sponsors can provide infrastructure, consulting services, etc., to an R&D consortium, in addition to cash subsidies. Taking into account the multivariate nature of subsidies, sponsors may find a combination of crowding out (for some variables) and reverse crowding in (for other variables) optimal. This is another type of coexistence of crowding in and crowding out.

Reverse crowding out is central to FLAR's genesis. FLAR emerged as a funding arrangement to enable the continuation of an existing breeding program, namely CIAT's irrigated-rice program. Due to a budgetary setback unrelated to the program, it had to be discontinued; it was at this point that CIAT's Director-General, Grant Scobie, and its rice economist, Luis Sanint, decided to try and mobilize funds from the Latin American rice sector (Binenbaum et al. 2003). Inspired by the Australian RDC arrangement, they designed and founded FLAR. Thus the breeding program was essentially continued, but its funding source was shifted from development assistance to local industry and public-sector support. This is a clear example of reverse crowding out.

FLAR receives in-kind support through the usage of CIAT's facilities and its access to the CGIAR's network of personnel and germplasm exchanges. These advantages doubtlessly enhance FLAR's value to its members and stimulate their cash and in-kind investments in FLAR. Thus FLAR demonstrates both the multivariate nature of outside support and the possibility of an incentive structure that combines reverse crowding out with crowding in.

3C. Under-funding due to differences in willingness to contribute

In contrast to partnerships with smaller number of members, R&D consortia tend to feature standardized funding arrangements which cannot fully exploit members' willingness to contribute. This is another cause of under-funding.

An important theme in the public goods literature is that private information on willingness to pay constitutes a major obstacle to efficient public goods provision. The public-goods literature suggests that nifty revelation mechanisms such as the one devised by Groves & Ledyard (1977) achieve second-best results in the presence of such informational asymmetries. Such mechanisms are complex even in relatively simple games. They would thus be hard to design for R&D consortia due to the latter's excessive technological and strategic complexity. Thus we rarely, if ever, observe sophisticated revelation mechanisms in R&D consortia.

Partnerships with fewer members offer more scope for fine-tuning contractual details. Transaction costs – e.g. those associated with negotiations – increase rapidly with the number of players. Hence multi-member consortium funding arrangements tend to be based on simple formulas where member contributions are a function of some measure of member size.

Such simplicity and transparency come at a cost. Funding arrangements in R&D consortia will generally not be able to achieve second-best solutions *à la* Groves-Ledyard. Funding shares are based on an imperfect correlate of willingness to pay, and will thus vary in relationship to players' true and undisclosed willingness to pay. The 'marginal member' – the one whose funding share is the highest relative to her willingness to pay, and just about agrees to join the consortium – may exert a disproportionate and downward influence on the consortium's overall budget. Thus under-funding is likely to be worse than in the Groves-Ledyard case.

In FLAR, funding is tied to a country's rice output – a likely correlate of willingness (or ability) to pay. In this way, FLAR has saved itself cumbersome negotiations; this was a provision that all prospective members could easily agree on. It is an open question whether one of the sophisticated revelation mechanisms could have been put in place with the consent of all members – at the very least this would have entailed costlier negotiations, and a more complex and less transparent consortium agreement.

The actual functioning of FLAR features a revelation mechanism of sorts: members can get more out of FLAR through supplementary investments, such as sending additional experts to meetings in excess of the amount of delegates required. The members with less developed rice R&D programs are the ones who tend to make such supplementary investments, presumably as a way to catch up. Such members would likely agree to a larger FLAR, if all others agreed to increase contributions.

3D. The ambigious effect of member size on relative contribution

In most R&D consortia the players' sizes matter. There are two opposing effects of size on relative contribution: the "greater stakes" and "bargaining power" effects.

Most formal models of R&D consortia do not take into account size. These models often conceive of the typical consortium member as a firm without a budget constraint. Even with players who do not differ ex ante, a game may yield asymmetric equilibria in terms of strategies and/or payoffs. Models of R&D consortia with more than two members, such as that of Katz (1986), use ex-post symmetry as a modeling device that enables them to prove many of their most interesting propositions. To our knowledge, only one recent paper, Amir et al. (2003), manages to model an R&D consortium while disposing of ex-post firm symmetry.

How to think of size asymmetries in a collective action framework? In Olson's (1965) model of collective action, there is a tendency for exploitation of large group members by small ones, in the sense of the former bearing a disproportionate share of the costs. This is because larger members tend to have greater stakes in the joint project, creating an opportunity for smaller ones to free-ride on the former's contributions. Let's call this the "stakes effect." This phenomenon can be observed e.g. in the USA bearing a disproportionate share of the NATO burden. However, in R&D consortia, this tendency is often contravened by the larger members' greater bargaining power. Large R&D players tend to have more bargaining chips and 'outside options' due to their larger and more diverse pool of resources and partners. For this reason, they can be expected to extract favorable conditions, including lower funding shares, from other players. This is the "bargaining power effect". In politicized contexts, this effect is mitigated by legitimacy constraints: players do not wish (or cannot afford) to be perceived by their constituents as 'suckers.' Being 'exploited' by other players does not look good.

As illustrated in Figure 2, FLAR's members vary widely in size. The largest member country, Brazil, has an output of irrigated rice which is about 80 times that of the smallest one, Guatemala, and a factor 10 or more larger than any of four other member countries. FLAR members differ vastly not only in terms of output, but also in terms of R&D capabilities. Output is correlated with R&D capability. Brazil's national agricultural research system (NARS) has a large budget and is a global player in both qualitative and quantitative terms. It has much to offer to FLAR or to other players in terms of rice varieties, expertise, facilities, etc. Brazil would be an interesting agricultural R&D partner for multinationals such as Monsanto. These factors contribute to Brazil's bargaining strength within FLAR. Similar considerations apply to other relatively large FLAR member countries such as Colombia. One might expect to observe an effect opposite to Olson's, namely 'exploitation' of the small by the great. However, that would probably contravene political legitimacy. FLAR definitely has political aspects, and it might well be unacceptable in domestic politics for the organization representing a small rice-producing country to be seen as securing an unfairly small share of FLAR's net benefits.

3E. Ex ante IPR allocation as an incomplete contracting problem

Relationship-specific investments and contractual incompleteness are pervasive features of R&D consortia. This helps us understand their IPR arrangements.

The success of any consortium whose primary mission is to conduct R&D depends on ongoing member contributions long after the initial consortium agreement has been signed. Such contributions can take many forms, such as personnel exchanges and the sharing of ideas, data and physical resources. These contributions are generally relationship-specific and impossible to fully specify contractually ex ante. Thus, insights from the incomplete contracting literature (pioneered in the late 1980s by Grossman, Hart and Moore, e.g. Grossman & Hart 1986), which features games with incomplete ex ante contracts combined with relationship-specific investments and renegotiation, are applicable to R&D consortia. [7]

Due to its incompleteness, the ex ante contract is too blunt an incentive instrument to induce the optimum level of specific investment. Hence, some under-investment relative to the first-best outcome is inevitable.[8] Grossman & Hart (1986) show that the second-best ex ante property rights allocation is the one that gives the relevant property rights to the player whose specific investment adds the most value to the jointly developed product. Thus, property rights are allocated so as to minimize the efficiency loss due to under-investment.

The key relationship-specific investment in FLAR is the sharing of plant-genetic resources (PGR). Such sharing is problematic, even among consortium members. In cases such as FLAR, players would never have consented ex ante to complete PGR sharing. Under fundamental uncertainty concerning rice markets and the future value of any PGR, and under conditions of great strategic complexity, players are extremely reluctant to give up all control over their key assets – PGR. Therefore, it is left up to FLAR members to share, or not share, their PGR with FLAR. Thus, a consortium like FLAR needs an incentive mechanism to encourage PGR sharing. Part of this involves rules to protect against leakage of FLAR varieties to third parties. Another part of this mechanism involves ex ante rules on property rights.

[7] Rosenkranz & Schmitz (2003) suggest a way of modeling this aspect of R&D consortia. Their model combines incomplete contracting with mutual know-how disclosure in a two-firm partnership.

[8] Maskin & Tirole (1999) dispute this conclusion by showing that sophisticated contracts can in fact achieve first-best outcomes in an incomplete-contracting setting. However, such contracts are generally not feasible in R&D consortia due to the latter's complexity.

It is clearly not feasible to stipulate ex ante a property rights allocation for each and every specific variety developed by FLAR – uncertainty and complexity are too great for this. For example, it is not even clear ex ante which successful varieties will emerge from FLAR's breeding efforts. Thus, we have a clear case of incomplete contracting, where most future contingencies cannot be covered by an ex ante contract (the consortium agreement). Instead, the best the ex ante contract can do is to stipulate a few simple, general rules on property rights allocation. By Grossman & Hart's (1986) logic, this allocation should correspond to the relative importance of members' specific investments. FLAR has an arrangement in place which roughly – but only roughly – follows this principle. Each member gets the domestic plant variety protection rights to plant varieties developed by FLAR. The size of a country's domestic market is correlated with its plant breeding capabilities and its potential to contribute to FLAR's breeding program.

3F. External toughness fosters internal cohesion

The consortium arrangement impinges on relations with third parties. Internal resource sharing in R&D consortia can be encouraged by restrictions on external sharing. The anti-competitive aspect of R&D consortia can be welfare-enhancing if it counterbalances third parties' market power.

To complete our description of elements of the R&D consortium game, we consider provisions regarding non-members. The two main categories of non-members are those eligible for membership, and those not eligible. The consortium must find ways to restrict non-member access to its outputs. Thus non-members cannot free-ride on consortium investments, and eligible ones have an incentive to join. Moreover, cooperative behavior – especially resource sharing – by consortium members is encouraged by provisions preventing 'leakage' to third parties.

Rules on the allocation of IPR and associated licensing provisions play a key role in the design of such incentives. The consortium may hold internally generated IPR and exclusively license it to members. Furthermore, the consortium agreement may stipulate reach-through provisions in such licenses restricting sub-licensing, or making it conditional on consortium approval.

The consortium itself may be a means for competitors to reduce competition in the output market. It may even be used to reduce the members' overall (costs of) innovative activity by eliminating competitive R&D. Thus there is a fundamental tension in R&D consortia: the rationales for cooperation must be weighed against antitrust considerations (Katz 1986; Katz & Shapiro 1987; Shapiro & Willig 1990). However, collusion can be welfare-enhancing if it counterbalances the market power of third parties.

In summary, external toughness – including restrictions on insider-outsider interactions – tends to foster internal cohesion.

FLAR illustrates all of these points. While it is not incorporated and thus cannot itself hold IPR, FLAR members get to hold the rights to FLAR rice varieties in their respective home jurisdictions. Agreements between a FLAR member and a third party (e.g. a multinational) that involve the transfer of FLAR materials or IPR generated by FLAR require the approval of the other members. An interesting FLAR provision which has a collusive aspect is its rule for royalties. The FLAR agreement stipulates specific formulas for royalties percentages, should FLAR members license their PVP for FLAR varieties to third parties. This provision is included in the agreement to prevent FLAR members from being played off against each other when they negotiate licensing contracts with third parties. This collusive provision may well be justifiable in social welfare terms, because it enhances members' incentives to share their PGR with FLAR and strengthens their bargaining positions with multinationals, thus counterbalancing the latter's market power. Private-sector plant breeding and related technological tools and IPR are highly concentrated in the hands of a few powerful multinationals. Concerns about leakage of FLAR resources and products to multinationals played a prominent role in early FLAR discussions. Relevant FLAR provisions were designed to allay such concerns (Binenbaum et al. 2003).

4. The big-picture game

4A. Characterization of the big-picture game as a repeated prisoners' dilemma

Consortium games can be simplified to a multi-stage prisoners' dilemma with multiple levels of (non-)cooperation and unknown horizon. Thus we can apply the Folk Theorem, i.e. identify incentive-compatible scenarios.

The amalgam of incentive problems discussed in the previous section might seem to be exceedingly complex and unwieldy, impossible to analyze as a single game. Not so: the overall picture can be drastically simplified. Collective-action games, including R&D consortia, are often prisoners' dilemmas. PDs have two key features: mutual positive externalities of cooperation (or, equivalently, negative externalities of non-cooperation) and Pareto-superiority of symmetric cooperation over symmetric non-cooperation. Both features are generally implied by the three technical rationales of section 2. However, the incentive problems of section 3 diminish both the positive externalities and the Pareto-superiority of cooperation. If, weighed against the rationales, the incentive problems are not too severe, a PD characterization of the game is appropriate. If they are too severe, then nothing happens (i.e. the outcome is non-cooperation) and the game is not interesting.

The kind of PD game that is relevant to R&D consortia is characterized by repetition and by an uncertain horizon. Players will generally interact repeatedly, and they do not know when their interactions will end. The Folk Theorem says that a wide range of Subgame-Perfect Nash Equilibria (SPNE) are sustainable in an infinitely repeated PD, including perpetual non-cooperation and perpetual cooperation. Neyman (1999) extends this result to the case of finitely repeated PD where the common knowledge assumption regarding the number of stages is slightly perturbed. Neyman does not explicitly model uncertain payoffs that vary from one period to the next – as in FLAR[9] and most real-world games – but his result should be generalizable to this case.

For our purposes it is further useful to allow for multiple levels of cooperation and for restrictions on the strategy space. A key simplifying element here is that the level of cooperation summarizes multiple underlying variables, such as funding, input sharing, information sharing, IPR sharing, etc. The extension of the PD to multiple levels of cooperation is straightforward: if there are, say, four levels of cooperation, then for each pair of levels considered separately we have PD payoffs. An example of a restriction on the strategy space is that differences of level of cooperation can be only

[9] Key uncertainties for FLAR include (1) the future performance of plant varieties yet to be bred, and (2) rice price fluctuations in global markets.

0 or 1. Thus, if one player plays level II, then level IV is ruled out – only levels I, II and III can be played by the other players. If one player plays level I, then the others can play only I or II.

How to construct the big-picture game in the FLAR case? Consider the game played by the primary players – the representatives:

1. A representative's set of actions can be reduced to four levels of participation: (I) none; (II) support FLAR at level close to its minimal critical mass, with limited sharing of PGR, data and expertise; (III) support common FLAR budget at level close to its minimal critical mass, but with supplementary investments to enhance technology transfer and with more extensive sharing; (IV) support FLAR at high level, maximizing joint payoff, with extensive sharing.
2. PD payoffs to a country's rice sector are associated with an increase in participation from one level to the next. That is, if player X moves up one level while the other's don't, this move makes X worse off while making the others better off; but if a sufficiently large subset of players move up on level, then all benefit in net terms.
3. Adjustments to the PD payoffs must be made due to size asymmetries, output market competition, and own-institution bias. E.g., own-institution bias implies a divergence between the interests of a country's rice sector and its FLAR representative: while the former receives PD payoffs, the latter (the actual player) perceives it would be made worse off by increases in overall participation to levels III and IV, as these would strengthen FLAR too much.

4. Legitimacy constraint and consensual decision-making: an arrangement based on willingness to pay is ruled out, and instead all players must support FLAR's budget at a proportionately equal level – as in the observed budget rule. Thus, players contributing at levels II and III can coexist; but if anyone plays II or III, then nobody will play IV.

This game features multiple stages. Every year, players may leave or join FLAR (implying another adjustment in payoffs: a change from or to level I is costly) and make decisions on the sharing of PGR and other resources; members can renegotiate the FLAR agreement, increasing or decreasing their support.

Due to the output competition and own-institution bias, levels III and IV are not incentive-compatible for some players. Combined with legitimacy constraints, this implies that nobody will play IV. This still leaves a range of incentive-compatible scenarios where some players play I or II, and the remaining players play I, II or III. Which of these prevails?

4B. Leadership as an equilibrium refinement

We introduce a novel leadership concept, namely the ability to choose one of the game's incentive-compatible scenarios in order to maximize a social welfare function. This function will often incorporate the interests of players not represented in the consortium.

Generally, when a game-theoretic solution concept yields multiple solutions, refinements are called for. In this case, we have a repeated PD yielding multiple subgame-perfect Nash equilibria. How to narrow down this range to a unique solution? Here, the focus is on leadership.

In the context of our logic, leadership can be defined in two ways: (1) the ability to alter the payoffs (e.g. through persuasion) or structure of the game such that players reach a dynamic equilibrium socially superior to the equilibrium in the absence of the leader's intervention, or (2) the ability to choose one of the equilibria on the basis of some social welfare criterion.[10] Let's call these type I and type II leadership, respectively.

The personal leadership of Scobie and Sanint may have been crucial for the formation of FLAR. Although it is impossible to prove this counterfactual, one senses that, absent their initiative, the joint Latin American program of irrigated rice breeding would have died prematurely following CIAT's budget cut.

In our logic, the factors conducive to leadership (Figure 1) determine the extent to which both types of leadership can be exercised. Were these factors present in the formation of FLAR? Scobie and Sanint did not have formal power over the future FLAR members. They did not control significant financial incentives, but CIAT did possess breeding expertise and facilities as well as connectivity to global nonprofit rice research and PGR flows. They understood the system, i.e. they properly

[10] Many different leadership concepts have been proposed in the management literature. Hermalin (1998) appears to be the only extant game-theoretic model of leadership. His definition of leadership – the ability to lead by example (in a moral-hazard-in-teams setting) – is narrower than ours. However, Hermalin's leadership concept, ours, and those advanced in the management literature are not mutually incompatible. They highlight different aspects of leadership, which is a complex phenomenon.

anticipated the FLAR game – for example, they sensed a significant willingness to pay in the Latin American rice sector for some sort of continuation of the breeding program. They had professional standing, but not to the extent that they could affect the other players' institutional structure and objectives. Importantly, they were perceived to be impartial – not biased in favor or against any players. In summary, conditions were in place for type II leadership, but by-and-large not for type I leadership.

The social welfare function depends on the leaders' views. For example, Scobie and Sanint were probably interested in promoting not just the rice industry's interests, but consumers' interests as well. But while the FLAR arrangement addresses to some extent mutual positive externalities among members, it does not address externalities that are external to their group. Rice consumers derive a surplus from FLAR activities but are not represented in it. Advances in rice breeding and agronomy inspire future agricultural innovations. Such 'external externalities' can only be internalized through public or philanthropic funding.

FLAR's history can be interpreted as follows: Scobie and Sanint exercised leadership. They offered core players – leading institutions in the continent's rice sector – a win-win solution whereby the latter moved from level I participation to level II or III, depending on the institutional payoffs for each country's representative. The players might not have achieved this on their own as none of them sufficiently satisfied the conditions for leadership. However, given the limitations to Scobie's and Sanint's leadership role, they could not possibly have achieved the first-best outcome, namely level IV participation by all primary players. Further Pareto improvements (not counting narrow institutional interests) can only happen if latent players become active. Consider two examples. First, farmers or an activist government in a country which is currently a level II player could force the country's representative to move to level III. If this happened to all level II players, an overall move to level IV – a significant FLAR expansion – might become feasible. Second, FLAR could be supplemented by philanthropic funding to bring it closer to level IV operations, say, comparable to WARDA. Such funding could include matching arrangements (as in the RDCs) to incentivize current level II players to increase their support of FLAR.

5. Conclusions

Real-world R&D consortia appear to be an extremely complex and diverse phenomenon that does not lend itself for game-theoretic modeling. Nevertheless, on closer inspection there are many common features that most R&D consortia share.

First, they are motivated by a mix of technical rationales: their outputs are (pure or impure) public goods; their R&D technologies exhibit economies of scale (and often scope as well); their R&D inputs are complementary. These rationales can be summarized as "mutual positive externalities".

Second, a range of incentive problems hamper the players' efforts to realize the mutual positive externalities of cooperation. Due to the relationship-specific nature of consortium investments and the incomplete nature of contracts, hold-ups and under-investment – i.e. suboptimal contributions to the consortium of various kinds – occur. Players' willingness to contribute to the consortium in various ways cannot be observed but only (imperfectly) inferred from their actions. "Leakage" of consortium resources and outputs to third parties is costly to prevent. Size asymmetries cause additional transaction costs. All of these factors exacerbate under-investment.

Third, the consortium contract is a response to these incentive issues. Relationship-specific investments such as the sharing of inputs, people and information can be encouraged by a carefully tailored ex ante allocation of intellectual and other property rights. Membership contributions are based on (albeit imperfect) correlates of willingness to pay. Provisions against leakage of consortium resources and outputs to third parties encourage internal sharing. Collusive elements in the consortium agreement increase member payoffs and strengthen their bargaining position vis-a-vis third parties.

These incentive issues are fruitfully analyzed in the respective strands of literature that address them (except for the issue of external leakage, which appears to have barely been addressed in applied game theory so far). While combining them explicitly in a single game model may not be feasible, games that focus on each issue separately are useful for understanding real-world consortia.

Fourth, it is still possible and useful to construct an overall game that abstracts from specific incentive issues. As noted in the collective-action literature, there is a striking generality to the prisoner's dilemma. We interpret the R&D consortium game as a multi-stage prisoners' dilemma with multiple levels of (non-)cooperation and unknown horizon. Thus we can apply the Folk Theorem, i.e. identify incentive-compatible scenarios. This is a fruitful way of thinking about real-world consortia: a range of alternative scenarios would have been compatible with players' incentives.

Another key real-world element of the consortium game which can be modeled as a PD game is the existence of multiple levels of (non-)cooperation.

Fifth, we can explain (or even predict) which of the incentive-compatible scenarios emerges by reference to leadership. The consortium's leaders help determine the level at which the consortium is funded and the extent of members' cooperativeness. The extent or strength of leadership can, in turn, be explained (or predicted) by a range of socio-economic and cognitive conditions.

Jointly, these five elements comprise a logic of collective action in R&D which, we hope, will help bridge the gap between applied game theory and real-world consortia (and other institutions).

Benevolent designers of R&D consortia can combine this scheme with incentives to address "external externalities." Almost all the internal and external incentive issues cause under-funding. In order to properly address both the internal incentive issues and external externalities, a benevolent catalyst should recognize the multi-dimensional nature of subsidies and the coexistence of crowding in and negative crowding out. That is, (i) in addition to cash subsidies various kinds of in-kind support are important in incentivizing (prospective) consortium members; (ii) it makes sense to increase some of these choice variables in order to induce greater contributions by consortium members; while (iii) other choice variables should be decreased to encourage cooperation.

As to follow-up work, much remains to be done in further developing our conceptual logic and using it to generate and test hypotheses. Furthermore, our paper contains a wealth of largely undeveloped modeling ideas. The reader is invited to pursue these.

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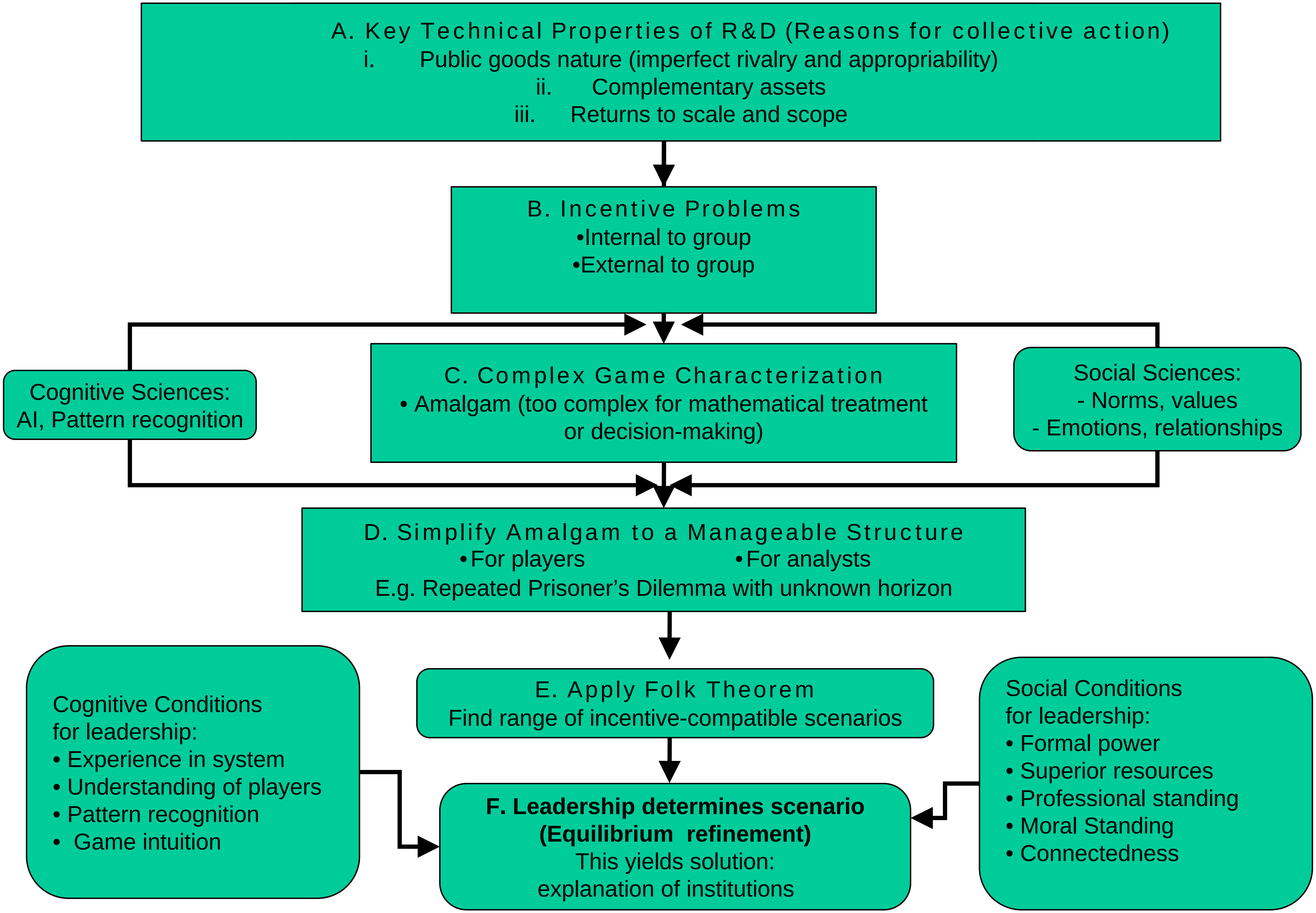
Figure 1. The Logic of Collective Action in R&D



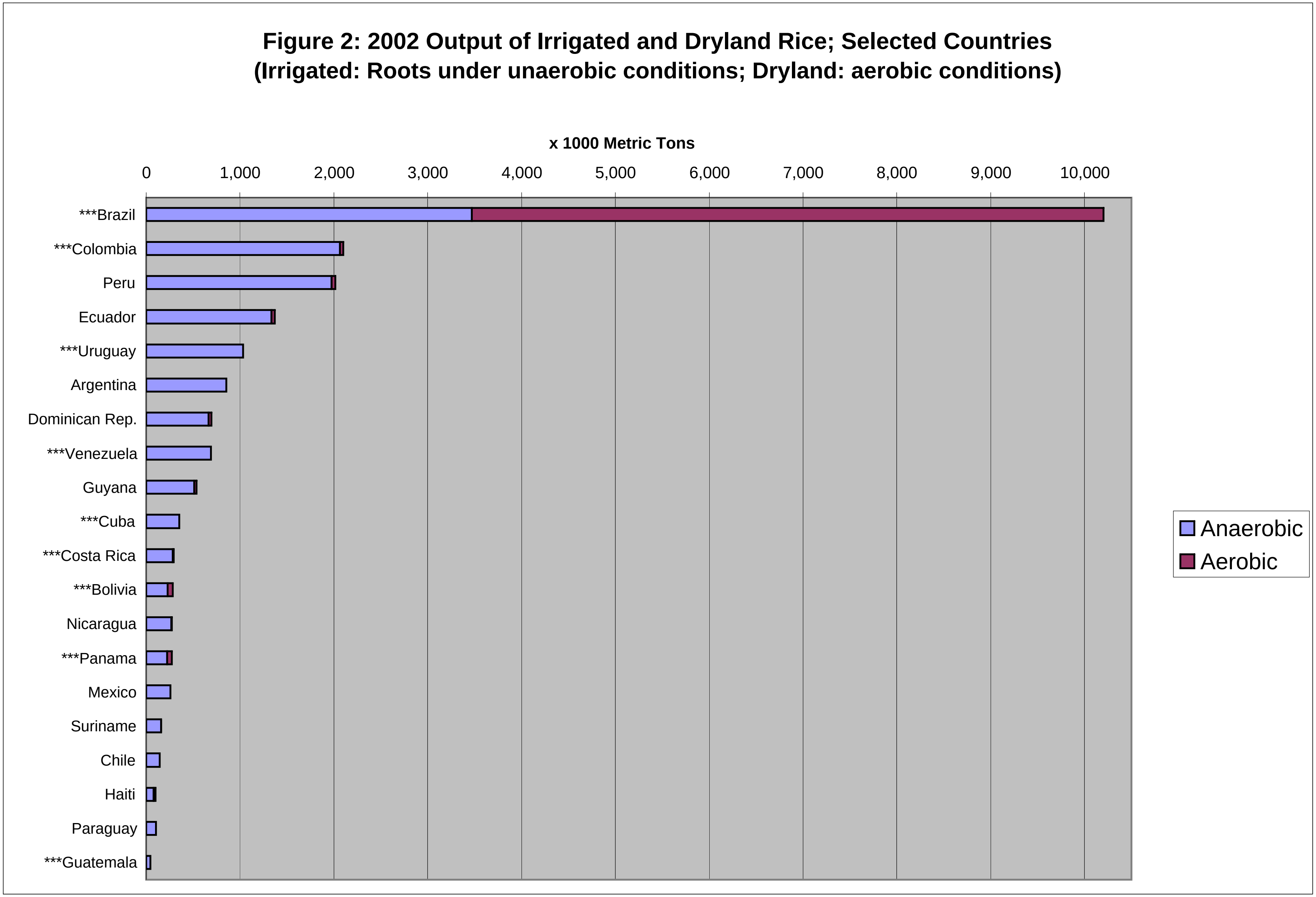


Figure 2: 2002 Output of Irrigated and Dryland Rice; Selected Countries
(Irrigated: Roots under unaerobic conditions; Dryland: aerobic conditions)
x 1000 Metric Tons
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
***Brazil
***Colombia
Peru
Ecuador
***Uruguay
Argentina
Dominican Rep.
***Venezuela
Guyana
***Cuba
***Costa Rica
***Bolivia
Nicaragua
***Panama
Mexico
Suriname
Chile
Haiti
Paraguay
***Guatemala
Anaerobic
Aerobic