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Collective Action in Plant Breeding

Eran Binenbaum, University of Adelaide

Phil Pardey, University of Minnesota

Comments are welcome at eran.binenbaum@adelaide.edu.au

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1. Introduction

This paper explores the logic of collective action in R&D. Using a case study on an international plant breeding consortium, the Latin American Fund for Irrigated Rice (Spanish acronym FLAR), as well as other institutional examples connected to plant breeding, we construct a more general argument on collective action in R&D.

The topic at hand presents a formidable methodological challenge. Olson (1965) formulated a compelling “Logic of Collective Action” using a few very parsimonious models. Such ideas ought to be applicable to research and development (R&D). However, a variety of complicating factors make it hard to summarize collective action in R&D in terms of a relatively simple logic. These complicating factors are modelable when addressed in isolation from each other. Considered in combination, they are too complex for a single tractable model. Consequently, the best the present paper can do is to review relevant features of collective arrangements such as FLAR and discuss these, using several strands of more rigorous literature, one at a time. The insights thus obtained are integrated by means of narration and intuition, not mathematics. A companion paper currently under construction develops a rigorous game-theoretic model of a plant breeding consortium, but leaves out many of the relevant institutional issues. The present paper sacrifices rigor for the sake of a fuller discussion. However, the paper does relate to mathematical reasoning and may contain a dozen or so ideas for original and rigorous models.

The FLAR case study – used to illustrate many of our points – can be found in a separate paper (Binenbaum et al. 2003). FLAR is a consortium of nationally

representative organizations from a group of Latin American countries. It was founded in 1995 to conduct a range of activities – primarily plant breeding – related to irrigated rice. Recently, the first FLAR varieties were released. In addition to FLAR, we will draw examples from other institutional arrangements, including the Consultative Group on International Agricultural Research (CGIAR) and its Centers, the Convention on Biological Diversity (CBD), the International Treaty on Plant Genetic Resources (PGR) For Agriculture (“the International Treaty”), the so-called In-Trust Agreement between the Food and Agricultural Organization (FAO) and the CGIAR Centers, and the Australian R&D Corporations (RDCs).

2. Two core issues: Impure public goods and complementary assets

Classics of the collective-action literature such as Buchanan (1965), Cornes & Sandler (1996), G. Hardin (1968), R. Hardin (1982), Olson (1965), and Samuelson (1954; 1955) focus on incentive problems that arise as a consequence of the public-goods characteristics of non-rivalry (also known as non-diminishability) and non-excludability. R&D outputs can typically be characterized as (often impure) public goods due to imperfect rivalry and/or imperfect excludability. The public-goods nature of R&D outputs is clearly a core issue in the institutional design of the production of such outputs.

The precise public-goods characterization of R&D outputs is not a straightforward matter. The excludability afforded by intellectual property (IP) rights (IPR) is far from perfect, due to various costs, the existence of multiple jurisdictions, and imperfect enforcement. Moreover, 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 (PVP). 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 cases of low excludability but high rivalry, the common-access-resource literature (which builds on Hardin 1968) may be relevant. When excludability is high but rivalry low, a club-goods model (as pioneered by Buchanan 1965) may be more appropriate.

There is a second core issue facing collective action in R&D: the need to combine complementary (synergistic) assets. The assets may be tacit knowledge, codified information, IP, or technology-embodying objects such as genetic resources. Hayek (1945) suggested – albeit in a different context – that the central economic problem is the combination of complementary knowledge fragments dispersed among many agents. Graff et al. (2003) and Heller & Eisenberg (1998) point to the critical problem of combining complementary IP in the life sciences. The present paper focuses on genetic resources as a prime example of complementary assets.

Due to genetic combinatorics, plant breeding tends to be characterized by economies of scope and scale. 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: $V(S \cup S') > V(S) + V(S')$. 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 constructing a "logic of collective action" in plant breeding (and R&D generally). It will be referred to as the "baseline model".

The first key question, then, is: Which obstacles do R&D players need to overcome to combine their complementary assets? There are several possible answers to that question, which can be used to create a taxonomy for analyzing collective action in R&D. The "logic" in question is not a single rigorous game-theoretic model, but rather a system of such models – whose relative relevance varies depending on the public-goods characteristics of R&D outputs and other aspects of the real-world games we wish to understand. Many of the answers – i.e. suggestions for obstacles to "perfect combination" – that follow may be subsumed under the heading of "transaction costs" – a term which we shall avoid due to its many interpretations.

The second key question follows from the first: How do R&D players overcome obstacles to combining complementary assets? The first question leads us to identify incentive problems; the second suggests a set of institutional solutions to those incentive problems.

3. The hold-up obstacle and the Leviathan solution

A variation on the baseline model may yield a drastically different result. 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. That is, 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.

4. Funding issues: reverse crowding out, willingness to pay

So far, we have ignored the fact that a plant breeding program needs inputs other than PGR. Sharing of PGR is not enough: there must be a funding arrangement. In the case of FLAR, this is not just an obvious fact – it is the key to understanding FLAR’s genesis. FLAR emerged as a funding arrangement to enable the continuation of an existing breeding program, namely the irrigated-rice program of the International Center for Tropical Agriculture (Spanish acronym, CIAT), one of the CGIAR Centers. 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). The CGIAR is a conduit for development assistance, institutionally close to the World Bank; and the conception and birth of FLAR fit into a larger trend – discernable from the 1980s onwards – towards greater self-reliance of recipients of aid.¹

More generally, in agricultural R&D, there often is an ‘outside’ player or group of players (outside of the industry, that is) willing to provide R&D subsidies. This may be the community of rich countries, charitable foundations, and/or the domestic government. Development assistance is but one of the possible motivations.² While private-sector agricultural R&D has grown in significance, the public sector is still an

¹ Other manifestations of this trend include microcredit (pioneered through the Grameen Bank in Bangladesh) and participatory plant breeding.

² From a political economy perspective, lobby-driven support of agriculture (in rich countries) or indirect support of poor urban consumers (in poor countries) may be important domestic drivers of agricultural R&D subsidies. From a social welfare perspective, such subsidies may be justifiable due to benefits external to the industry, including consumer benefits, R&D spillovers, and the option value of conservation of agro-biodiversity. These two perspectives combined may produce a balanced view of agricultural policy (Rausser 1982), including its R&D aspects.

important player to agricultural R&D in the rich world, and even more so in the developing world (Pardey & Beintema 2001). In many cases public-sector institutions will want to explore the possibility of a partial or full retreat from agricultural R&D funding; FLAR is one possible institutional model for such a retreat. In linking the FLAR funding scenario to economic theory, it is crucial to distinguish between “crowding in” and “reverse crowding 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, as in the FLAR case, a reduction in public expenditure results in increased private expenditure, then we should speak of “reverse crowding out.”

A model of reverse crowding out can easily be 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 can 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. This result can be reproduced in the context of more

complex models that accommodate more of the FLAR facts, and captures part of the essence of FLAR's history.

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. In fact, private information on the willingness to share PGR may also hamper efficient collective action – another real-world feature ignored so far in this paper.

The public goods literature suggests that nifty revelation mechanisms such as the one devised by Groves & Ledyard (1977) may achieve second-best results in the presence of such informational asymmetries. In FLAR, however, we do not observe such a sophisticated scheme. Instead, 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 preceding discussion suggests that the funding arrangement of FLAR and other agricultural R&D consortia may be a third-best solution at best. 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. With funding shares constrained in this way, and given the sovereignty of all prospective consortium members, one would expect the consortium's overall budget to be under-funded

relative to the social optimum. 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.

One can also construct an extreme case, in which the funding-shares-determination problem is so severe that the consortium fails to form in spite of there being a social welfare rationale for it.

5. Thresholds; asymmetries; member capabilities; third parties

Start-up thresholds constitute another potential obstacle to efficient collective action. Collective institutions such as FLAR need a certain critical mass to be viable. As it is, FLAR is fairly small, having a six-digit annual budget in dollar terms; it may be not far above its critical mass. The threshold idea can be modeled using a standard U-shaped average cost curve, i.e. $V(B, \dots)$ exhibiting increasing returns to B initially, decreasing returns at higher levels of B , and/or a fixed start-up cost. Olson (1965) takes these features into account in his model of collective action.

In many cases of R&D consortia, including FLAR, the players' size matters. Most formal models of R&D consortia do not take into account size. Most of these models think of the typical consortium member as being a firm which does not face 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.

Non-profit players and ex-ante asymmetry between firms seem to be unexplored themes in models of cooperative R&D. 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 either of four other member countries. What does this imply in game-theoretic terms? 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. In cases such as FLAR, this effect is unlikely, because bargaining power appears to be correlated with size.

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 in qualitative as well as quantitative terms a global player. 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.

6. Group size; crowding in; global system

With widely dispersed consumer benefits that occur in addition to more concentrated producer benefits, there exists a social-welfare rationale for arrangements such as the Australian RDCs. FLAR differs from the RDCs in that it is international with a layered structure – while its member organizations represent large groups of farmers and related businesses, they themselves constitute only a small group. Olson (1965) suggests that provision of collective goods is suboptimal in small groups, but that this suboptimality will be more serious as group size increases, with zero provision of the collective good a quite likely outcome in a very large group. In the case of the Australian RDCs, the consortium members are individual farmers. The RDCs are industry-specific, for example for grains, cotton, dairy, and so on, and are funded by levies (also called commodity checkoffs) collected from industry producers and supplemented by government matching grants (Alston et al. 1999). This funding arrangement roughly corresponds to the dispersed consumer benefits and more concentrated farmer benefits.

By Olson's logic, the group of, say, Australian cotton farmers is so large that, absent government involvement, they might not have engaged in collective action. The matching grants arrangement may have pushed producers' groups across the threshold of collective action. Thus industry funds appear to have been mobilized in the RDC case through a mechanism different from that in the case of FLAR – crowding in, as opposed to reverse crowding out. However, an element of crowding in may be present in FLAR as well. CIAT is a FLAR member, contributing about 15% of its budget; FLAR is located on the CIAT campus and links PGR contributed by FLAR

members to the CGIAR's global system of genebanks and PGR exchanges. Thus, rice varieties from other parts of the world are available for crosses with member-supplied varieties. This link with the global public agricultural R&D system helps to make FLAR participation an attractive proposition for members, and encourages them to contribute their PGR. This can be seen as a form of crowding in.

7. Genetic resource sharing & incomplete contracts; Output competition & collusion

The sharing of PGR 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. Thus, 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 (see below). Another part of this mechanism involves *ex ante* rules on property rights.

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.

Genetic resource sharing may in this context be viewed as relationship-specific investments which occur after the *ex ante* contract has been agreed upon. 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, may be applicable to R&D consortia such as FLAR.³ Due to its incompleteness, the ex ante contract is too blunt an incentive instrument to induce the optimum level of specific investment. Thus, some under-investment relative to the first-best outcome is inevitable. In the case of plant breeding consortia, this means that suboptimal PGR sharing is likely.

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. FLAR has an arrangement in place which might roughly – but only roughly – follow this principle. Each member gets the domestic PVP rights to plant varieties developed by FLAR.

In analyzing the likely (in-)efficiency properties of consortium arrangements such as this, 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. In FLAR, the situation is more

³ Rosenkranz & Schmitz (2003) may provide some clues as to how to model this aspect of R&D consortia. It combines an incomplete contracting approach with analysis of mutual know-how disclosure in a two-firm partnership.

complex. Rice varieties are the main FLAR output. These first need to be tested (mostly by members) before they can be released. They are subsequently sold as seeds to farmers, who sell the resulting output on domestic markets or export it. Rice exports of FLAR members are fairly insignificant, with one important exception. The size of members' domestic seed markets is probably correlated with their capacity to contribute valuable PGR to FLAR, but if so, this correlation will be far from perfect. Thus, we obtain an insight similar to that concerning the FLAR funding arrangement: the FLAR IP allocation mechanism makes sense, but is likely to be no better than a third-best solution compared to the socially optimal level. Thus, we can expect FLAR to induce some sharing of PGR (without which FLAR would probably not be a worthwhile endeavor), but we can also expect that some opportunities for mutually beneficial PGR sharing by members will be forfeited. There are some indications of this in the case of FLAR (Binenbaum et al. 2003).

The one exception to the 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. In terms of the preceding analysis, the organization representing Uruguay in FLAR might have a greater disincentive than other members to share promising PGR with FLAR, as these materials could be used to create FLAR varieties which would then become available to Uruguayan and Brazilian farmers alike. To a lesser extent, a similar argument may apply to Brazilian PGR sharing, which might benefit Uruguayan competitors.

The consortium itself may be a means for competitors to reduce competition in the output market (Katz 1986; see also subsequent work by Katz and Shapiro). An interesting FLAR provision which may have 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 (Binenbaum et al. 2003). 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.

8. Genetic resource sharing & prisoner's dilemma; multi-stage game; leadership

Another way to relate the issue of incentives for genetic resource sharing to economic theory is to apply the logic of the Prisoner's Dilemma. Consider the payoffs of PGR sharing. With the consortium arrangement in place, and taking account of the IP provisions discussed in the previous section, we can think of a member's decision to share – or not to share – PGR with FLAR as follows. There is an incentive problem in that PGR sharing tends to result in net positive externalities for fellow members. The member's own benefits from sharing arise because FLAR has a unique capability for upgrading PGR. Having your PGR upgraded rather than somebody else's means that the resulting FLAR varieties are more likely to be specifically suitable for your country's agro-ecological conditions. However, sharing also means that you forfeit the opportunity of independent development of your PGR, or of independent deals with third players like multinationals. It also means that you might be helping your competitors. Sharing your PGR with FLAR means that you steer FLAR's research agenda more in your direction, but it also implies adding to FLAR's gene pool. The former effect may imply a negative externality for other members, but the latter effect – a positive externality – is probably stronger.

In a subset of cases, PGR sharing will not appear attractive to members, but it would be optimal in terms of the total net benefits of FLAR members. This is the subset of member-owned PGR for which the Prisoner's Dilemma (PD) may be relevant, because the payoffs conform to the PD. The PD essentially describes a situation where there are mutual positive externalities associated with cooperative behavior,

which does not occur because the payoffs net of those externalities favor non-cooperation.

So far in this paper we have ignored the theoretical complication of multiple stages in the PGR sharing game. Of course it is a multi-stage (or, if modeled in continuous time, differential) game.⁴ The Folk Theorem tells us that a wide range of equilibria are sustainable in an infinitely repeated PD, including the unique one-shot non-cooperative Nash Equilibrium as well as the Pareto-efficient cooperative outcome. 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. In other words, if the players face (even slight) uncertainty about when the game ends, cooperation can be sustained in a Subgame-Perfect Nash Equilibrium (SPNE). Neyman's model appears to broadly reflect FLAR's stylized facts, except for it being an R&D consortium which upgrades the PGR shared by members in successive stages. Thus, to treat the stages of the PGR sharing game as identical is quite a stretch compared to the essentials of the real-world game. Nevertheless, one would expect Neyman's result to be generalizable to the case of multi-stage sharing and upgrading of PGR. In fact, the fundamental uncertainty inherent in R&D would appear to strengthen his result in that reality is, in fact, far removed from the assumption of common knowledge of the number of stages of the game.

The presence of multiple SPNE, of course, raises the question of which SPNE will be realized. This is the subject of the literature on coordination games (reviewed in Cooper 1998). A one-shot PD with costless coordination and perfect contractual

⁴ The FLAR decision-making process, like many other nonprofit and for-profit governance systems, follows an annual cycle; thus we might think of it as a multi-stage game where each stage represents one year.

enforcement of course yields the optimal result. The problem is that coordination (including communication) and enforcement are costly. In cases such as FLAR, the sovereign status of members and the absence of a strong international system of legal interpretation and enforcement renders coordination problematic. For encouragement of cooperative behavior such as PGR sharing, FLAR may depend on future repercussions of (non-)cooperation, especially on other members' sharing or withholding of PGR. It should also be pointed out that most of the individual decision-makers in the FLAR community belong to the same professional community (that of plant breeding and public agricultural R&D management), which may be a positive factor for cooperative behavior.

Leaders such as the FLAR director might play a role in encouraging sharing behavior. What is needed here in terms of economic theory is a model of leadership. In the context of multi-stage games, leadership can be defined as the ability to alter the payoffs or the rules of the coordination game such that players reach a dynamic equilibrium which is socially superior to the equilibrium that would obtain in the absence of the leader's intervention. This concept of leadership has, to our knowledge, not been modeled so far.⁵ Such a model might well be applicable to a wide variety of games, given the generality of the Folk Theorem and of Neyman's (1998) results.

The personal leadership of Grant Scobie and Luis Sanint may have been critical to the formation of FLAR. Although it is impossible to prove this counterfactual, one

⁵ Hermalin (1998) is, to our knowledge, the only extant game-theoretic model of leadership. The aspect of leadership that he focuses on, however – namely, the ability of leaders to lead by example in a moral-hazard-in-teams setting – is entirely different from the conception of leadership we're suggesting here.

senses that in the absence of their initiative the joint Latin American program of irrigated rice breeding might have died prematurely following CIAT's budget cut.

The International Treaty on PGRFA may be viewed as an instance of players' inability to reach an optimal outcome in a PD. The formation of FLAR precedes the International Treaty, but once the latter becomes operational, FLAR will operate within its rules. Fortunately for FLAR, rice is included as one of the crops included in the sharing mechanism provided for by the Treaty, so that the FLAR breeding program will have access to varieties coming from rice-rich countries such as China, which have rice R&D budgets that dwarf that of FLAR or its members. Rice might have been included in the Treaty's mechanism for PGR sharing in spite of its being the world's most important crop in terms of value of output, because the bulk of rice sales are on domestic markets (Binenbaum et al. 2001). However, some other crops that are important only as poor people's staple crops were, in fact, excluded from the Treaty, along with several major cash crops: "The list of crops covered by the multilateral system, which is ostensibly constructed on the basis of food security, includes some 35 crops... and approximately 80 (of 30,000) species of forages. Most major crops are covered, including rice, wheat, maize, potatoes, tomatoes, onions, sugarcane, melons, grapes, cocoa, coffee, and most industrial crops such as oil palm and rubber. In many cases, individual regions or countries concluded that they might gain more from withholding these resources from the multilateral system and then seeking to sell them bilaterally. China, the center of diversity for soybeans, insisted that soybeans be excluded, and when this was done, Latin America withdrew groundnuts. Not to be outdone, Africa took tropical forages off the table. This process may help the reader understand the irony of how a list of crops crucial to

world food security contains asparagus and strawberries, but is missing soybeans, groundnuts, tropical forages and most ‘poor people’s crops’ (Falcon & Fowler 2002: 211). This example clearly evokes a variation of the Prisoner’s Dilemma, i.e. one that occurs in the context of multilateral bargaining under severe time pressure. The failure of blocks of negotiating countries to achieve the socially optimal outcome may have been due to a number of factors: (1) the one-off nature of this negotiating process, rendering it similar to a one-shot game; (2) the blocks’ perceived opportunity cost of sharing their “crown jewels,” where the crown jewels could either be high-value cash crops such as soybeans or high-profile staples in terms of domestic politics; (3) negotiators’ desire not to appear to easily surrender such crown jewels and be exploited by the other players, again due to domestic politics; and (4) the absence of leadership and legal enforcement, rendering coordination very difficult; this being an ‘intercontinental’ game may make these obstacles even more severe than in the case of FLAR. Factors (2), (3) and (4), combined with the significant positive externalities of the rest of the world of PGR sharing by one world region, imply that PD payoffs may accurately describe this real-world game.

9. Public-private division of labor; outside players

To complete the policy picture, we have to place consortia such as FLAR in the context of the global public-private division of labor in agricultural R&D. FLAR is not a purely public-sector consortium. Its member organizations (one ‘representative’ per participating country) range in nature from 100% public to 100% private. Many points made in the foregoing discussion suggest that FLAR may be under-funded, and that the level of sharing of plant-genetic resources within FLAR may be suboptimal. In addition, FLAR faces pressures due to fluctuations in the world price of rice. The lower the price, the smaller the medium-term expected benefits of FLAR, and the greater the pressure on FLAR, with members possibly contemplating quitting it (and saving their annual contributions). FLAR also faces difficult coordination problems. It instituted the rule of single-organization per country, sanctioned by the country’s government and co-opted by the other members, in order to keep its short-term ‘subgames’ manageable. However, this compromises FLAR’s objective of being inclusive of 100% of each member country’s irrigated rice sector. Member countries without a leading public-sector or collective-private player tend to favor an alternative and more inclusive arrangement, where any Latin American player in irrigated rice R&D, including any number of private firms, could joint it. This would FLAR closer to the private end of the public-private spectrum. FLAR’s sister consortium CLAYUCA (its counterpart in cassava breeding) has this more inclusive, more private-sector oriented setup. Finally, all of these tensions are exacerbated by the long-term nature of plant breeding: Only recently, a decade after FLAR’s genesis, have the first FLAR varieties been released. It is quite an achievement for FLAR’s leaders to have sustained the institution in the face of political short-termism.

On plus side, two positive factors contribute to FLAR's continued appeal to its members, and may help explain its continued existence. First and foremost are the long-term rates of return of public agricultural R&D, which by all accounts tend to be high or very high.⁶ Second, these can be obtained primarily through FLAR because of its strong linkage to the international system of PGR exchanges which is managed mostly by the CGIAR. The inclusion of rice into the International Treaty strongly enhances FLAR's appeal.

In the absence of collective-action arrangements such as FLAR or the RDCs, for-profit firms would likely seek to fill the gap, as there appears to be sufficient excludability through PVP (and patents in some jurisdictions) (Lindner . However, this would entail its own incentive problems. Multinationals' market power would probably be enhanced. Perhaps even more seriously, private firms would be far more likely to run into trouble contributing to and accessing the existing system of international PGR exchanges. It should be added that, in the current arrangement, there is already an 'interactive gap' between collective institutions such as FLAR and multinationals such as Monsanto. The latter have a far higher profile in genetic modification (GM) technology than institutions like FLAR, and the lack of interchange between the Monsantos and the FLARs may be depriving the developing world of potentially valuable applications of GM technology. There is a clear division of labor between the private and public (or hybrid public-private like FLAR) agricultural R&D sectors, which may be beneficial to the world in terms of comparative advantage. The multinationals focus on a small number of high-value

⁶ Alston et al. (2000) identify methodological flaws due to which many studies of public investment in agricultural R&D find unrealistically high rates of return, but their revised rates of return are still high enough to amply warrant continued collective action in agricultural R&D.

crops; the public and hybrid R&D institutions have a far broader R&D agenda, including ‘orphan crops’ and staple crops for poor consumers.

Collective R&D institutions may have a problem of organizational focus. In the case of FLAR and the RDCs, this is well-defined, but in the case of the CGIAR and its Centers it is lacking. The multi-donor sponsoring arrangement of the CGIAR and its Centers has led to a system of a wide range of tiny projects, without clear organizational focus. FLAR and the RDCs, in contrast, appear to have resolved this problem in a satisfactory manner.

The global agricultural R&D system has moved from being predominantly public and nonprofit to having an important private and for-profit component. It is important to remember the need for an appropriate balance as the importance of combining PGR and other inputs into agricultural R&D is difficult to underestimate. This is the main component of the clear rationale for continued public-sector investment that this paper intends to lay out.

However, it should also be remembered that the public sector is not immune to territorial behavior. Herdt (1999) has likened the trend – from the 1980s onward – to claim property rights to PGR to a new ‘enclosure’ akin to the process by which the English landed aristocracy captured hitherto collectively ‘owned’ lands, at the expense of villagers. In fact, by the logic of common-access resources (Hardin 1965), one would expect such a process to enhance incentives for efficient usage of the land, albeit at the expense of greater inequality (although this argument ignores the pre-capitalist aristocracy’s proclivity for idleness). One can argue that Herdt’s new

enclosure may, in fact, be worse, because it replaces the tragedy of the commons with a tragedy of the anticommons. The CBD can be thought of as an attempt to overcome the tragedy of the commons. It encouraged countries to think of their genetic resources as national treasures. While this may have helped them defend themselves against biopiracy, the CBD has had as an unintended by-effect that it – along with the proliferation of IPR and the rise of the private sector – contributed to the emergence of an anticommons problem in agricultural R&D.

Especially in the present context, any attempt to formulate a logic of collective action in agricultural R&D must acknowledge the central importance of complementarity of dispersed R&D inputs such as PGR, along with the familiar public-goods characteristics of imperfect excludability and imperfect rivalry.

10. Conclusions and suggestions for further research

We suggest that the logic of collective action in plant breeding and in R&D generally revolves around two core types of incentive problems: imperfect public goods and complementarity of R&D inputs dispersed among multiple players. Thus, the classical collective-action models of common-access resources and club goods are central to understanding collective action in R&D, but so is the more recent concept of the anticommons (the modeling of which is still in its infancy). We propose to broadly interpret problems of collective action in plant breeding as having moved from a common-access problem – which was, perhaps, more of a perceived problem than an actually serious one – to a far more serious anticommons problem. This historical context is critical to understanding the role that public-sector and collective initiatives may play in the future of plant breeding.

We also suggest that the logic of collective action in R&D should be understood not only in terms of a small number of core models, which can be developed in stark, parsimonious, and rigorous terms, but additionally in terms of a complex of additional incentive problems, including – as illustrated in this paper – the hold-up problem, Leviathan games, crowding in and crowding out (preferably addressed in a single rigorous model to explain under what circumstances which of the two mechanisms applies), threshold effects, ex-ante and ex-post asymmetries among players, incomplete contracting and multi-stage Prisoners' Dilemma's in the context of R&D consortia, leadership as a key determinant of equilibrium selection in Folk Theorems and related finite games, etcetera. It should be noted that none of these games appear to have been modeled as of yet, and so the present paper may demonstrate an

enormous gap in published game theory and contract theory as they pertain to collective action in R&D. In spite of an explosion of literature in the past two decades applying rigorous modeling techniques to issues of collective action in R&D, it appears that the existing literature is dwarfed by the potential for valuable future work.

It should be entirely obvious to any game theorist that the derivation of any results (even allowing for simulation techniques, which can accommodate greater complexity than analytical solution techniques) would be completely impossible if we were to model all of the features discussed in this paper in one grand model. Nevertheless, they all are relevant to the real games under consideration. Parsimonious, rigorous game modeling definitely has a role to play, as illustrated by the references in this paper to the game-theoretic literature and in the many as yet undeveloped ideas for game models suggested here. But these rigorous games at best provide relevant insights into fragments of the complex real-world game. For these reasons, any future account of collective action in R&D ought to include a meta-modeling narrative, i.e. some verbal account and conceptual model linking the separate models of supplementary incentive issues such as the undeveloped sketches hinted at in the present paper.

In summary, the logic of collective action in R&D consists of two core sets of incentive issues, plus a set of supplementary incentive problems that fit together in some systematic but as of yet poorly understood way.

Arrangements such as that of FLAR as well as other institutions of collective action in research and development can only be properly understood in the context of such a logic, which is less parsimonious and more elaborate than that envisioned by pioneers of collective action models such as Olson.

It is only with such an enhanced logic of collective action that we can understand important features of an institution such as FLAR – including the answer to key questions such as, for example, the following:

- 1) How are the financial contributions determined?
- 2) Is there a method for rewarding and valuing members' IP contributions, and if so, what is it?
- 3) Does the consortium own the new IP?
- 4) What are the conditions – including royalty provisions – for licensing IP to members?
- 5) Is consortium-produced IP licensed to non-members, and if so, what are the conditions for doing so?
- 6) How are royalties for consortium-produced IP allocated?

Questions such as these are relevant to any attempt at collective action in R&D, and to answer them separately, and especially to analyse them as an integrated system of issues, requires an enhanced logic of collective action.

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