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Underinvestment in Agricultural Research and Development Revisited

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Policymakers all over the world, but particularly in developing countries, are struggling with the claim that too little is being invested in public agricultural research and development (R&D). This briefing paper tries to clarify the issue by introducing a simple, stylized model of the economic selection of agricultural R&D projects. The model is based on the concept of an ex ante choice set of all conceivable agricultural R&D projects, which, when ranked by their expected rate of return (ERR), form a distribution that increases steadily (and, we assume, exponentially) with decreasing ERR. The economic selection of R&D projects follows the simple optimizing rule of always selecting the project with the highest ERR first, then the next highest, and so on, until the budget is exhausted or until the ERR of the last selected R&D project equals the social rate of return, whichever comes first. The economically optimal investment level is to finance all R&D projects with an ERR that is equal to, or higher than, the social rate. This simple model highlights two distinctive aspects of the underinvestment problem: (1) suboptimality in project selection—some projects below the optimal cutoff point are selected at the expense of projects above the optimal cutoff point, and (2) the underlying factors that shape the set of agricultural R&D investment opportunities from which to choose. A better understanding of these factors, and those that cause selection suboptimality, may provide important insights into the variables that could help pull (rather than push) additional resources into agricultural R&D.

Introduction

The question of whether we invest too little, too much, or just enough in public agricultural R&D is an old one, but one that still awaits an adequate answer. The fact that investments in public agricultural R&D often result in high rates of return leads most agricultural economists and policymakers to concur with the notion that there is substantial underinvestment in public agricultural R&D in both developed and developing countries (Ruttan 1980; Pinstrup-Andersen 2001). Hence, the slowdown and occasional reversal in the growth of public agricultural R&D investment during the past 10–20 years (Pardey and Beintema 2001) cause concern among agricultural policymakers that the underinvestment gap is expanding rather than contracting.

This concern is particularly acute with regard to developing countries, where the need for agricultural innovation is stronger than ever. The demand for food and, when incomes rise, for more varied and better-quality food, is growing steadily. In addition, the transition from an agricultural to an industrial or service economy cannot be accomplished without modernizing the agricultural sector and increasing agricultural income. The current debate concerning investment in agricultural R&D in developing countries is therefore dominated by pleas to increase investments substantially.[1] However, although these pleas stress the need for agricultural innovation, economic feasibility is seldom addressed: the implicit assumption is that the additional investments will command sufficiently high rates of return.

The need for agricultural innovation, however, does not automatically translate into “desirable” agricultural R&D investment opportunities in an economic sense (i.e., exceeding the social rate). There is significant tension between what is needed and what is economically viable. It could be that the widespread slowdown in the growth of public agricultural R&D investment makes economic sense because it reflects a similar slowdown in the growth of profitable agricultural R&D projects in which to invest. Although this is not known with certainty, the possibility should not be excluded a priori.

1. For example, the Forum for Agricultural Research in Africa (FARA) and the New Partnership for Africa’s Development (NEPAD) have recently recommended doubling investment in agricultural R&D over the next 10 years.

A common way of addressing the question of whether or not we invest enough in agricultural R&D is to compare the agricultural R&D investment intensity (public agricultural research expenditure as a percentage of agricultural GDP) of a particular country with that of other countries in the same region or income bracket, or with competitors in the world market. However, although widely used, such comparisons give rather unsatisfactory answers from an economic point of view. Countries may collectively invest too much or too little in agricultural R&D, thereby generating misleading signals. Moreover, what is optimal in one context may not be optimal in others. For example, in several instances, developing countries have been advised to increase their investment in agricultural R&D to the same intensity level as developed countries, with the implicit assumption that the innovation opportunities for both sets of countries are the same.

A more rigorous economic approach would be to examine the rates of return obtained from investments in agricultural R&D. The available empirical evidence indicates a wide range of returns from such projects, from very high to very low and negative. The average of the reported rates (using various methods and levels of analysis) lies in the range of 40–50% (Alston et al. 2000; Evenson 2001). In the literature, this high average has frequently been used as an indication that there is substantial underinvestment in agricultural R&D (Ruttan 1980; Pinstrup-Andersen 2001). However, this argument is also flawed: as economists frequently point out, it is not the average rate of return that matters, but the rate of return on the marginal R&D project. In addition, returns realized in the past are not necessarily a good guide for current investment decisions. Moreover, the "evidence" does not answer the question of how much more should be invested.

This briefing paper is structured as follows. First, a simple, stylized model of the economic selection of agricultural R&D projects is introduced. The model is based on the concept of an ultimate set of agricultural R&D projects from which to choose ex ante. It allows us to illustrate graphically the economically optimal selection procedure and investment level. Then, we introduce subopti- mality in project selection and illustrate how actual selection deviates from optimal selection. In the remaining two sections, we discuss in some detail the factors that cause selection suboptimality and those that shape the ultimate choice set of agricultural R&D projects. Both sets of factors provide opportunities for enhancing investment in agricultural research.

Modeling the economic selection of agricultural R&D projects

In order to examine the optimal (or for that matter suboptimal) allocation of agricultural R&D resources, some idea is needed of the ultimate set of possible agricultural R&D projects from which society chooses ex ante (i.e., the choice set). A simple, stylized representation of the choice set helps explain this concept(figure 1). It is assumed that at a given time and for a given domain, the number of possible R&D projects increases (probably exponentially) from a high to a low expected rate of return (ERR), as depicted by the curve in figure 1. The exact position and shape of the curve are unknown and probably differ between research domains and countries, as well as through time. The ERR calculations depend on project-specific assumptions concerning project cost and benefit streams far into the future. Such assumptions are, by definition, rather speculative, creating a high standard error around the estimated rates. Moreover, it is also assumed that optimality in the selection procedure is defined strictly in efficiency terms: the R&D project with the highest ERR should always be selected first.

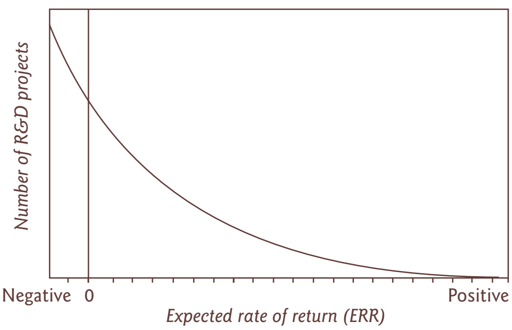

Figure 1: The hypothetical distribution of all possible R&D projects (the ex ante choice set)

One could liken the ex ante choice set of possible R&D projects to an immense glacier, of which only the leading edge enters the positive part of the ERR scale. The number of all possible R&D projects is more or less infinite, but only a few of them have an ERR that exceeds the social rate (i.e., the minimum rate of return required by a government on its investment activities) (figure 2).

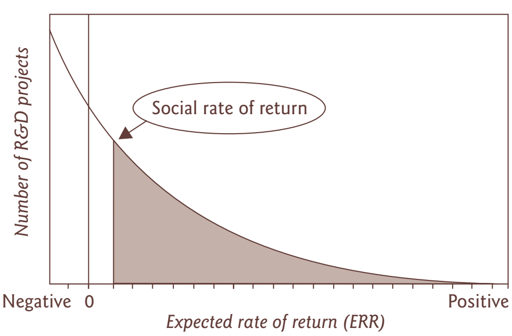

Figure 2: The optimal R&D budget

The social rate can be expected to be higher in developing than in developed countries because capital is scarcer (or because there is a greater preference for immediate rather than future income).[2] Hence, even when the ex ante choice sets are identical in shape and position, the economically optimal investment level in agricultural R&D will be higher for developed than for developing countries. One should avoid labeling this difference—which is caused by a difference in the social rate—as underinvestment.

Under perfect selection conditions, society would invest the exact amount needed to implement all R&D projects above the social rate. This is the optimal R&D budget in strict economic terms. With a lower budget, only a smaller proportion can be financed (the dark area in figure 3) and hence we can identify the "underinvestment gap" (the light shaded area). Only three variables are needed to estimate the underinvestment gap: (1) the social cutoff rate, (2) the actual cutoff rate, and (3) the slope coefficient of the curve.

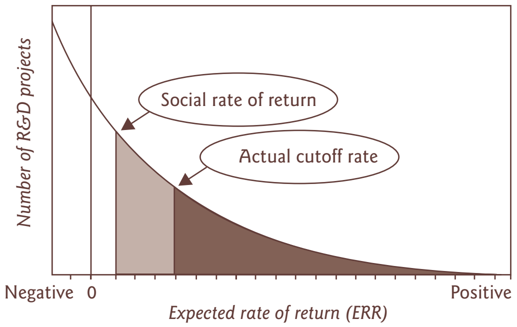

Figure 3: The underinvestment gap

Since the economic variables that determine the ERR of an agricultural R&D project (such as R&D costs and adoption rates) change through time, research projects that may initially have a negative or very low ERR can subsequently become profitable. After each selection round, the "glacier" of the choice set reestablishes itself, but the position and shape of its leading edge may change each time. Progress in basic sciences may open up new R&D opportunities that settle as "snow" at the top of the glacier. It may take some time before these opportunities turn into profitable innovation opportunities; some may never reach that point, evaporating before they can be exploited.

The hypothetical distribution of R&D projects continues to minus infinity, since the number of possible R&D projects with a negative rate of return is infinite. However, because researchers generally strive (usually implicitly) to develop economically viable R&D projects, most projects with a negative rate of return never become formal R&D project proposals. Subsequent selection processes reinforce such behavior. This is in direct contrast to the "evolution" metaphor that is often used to describe innovation processes (Nelson and Winter 1982). In evolution theory, mutations occur completely at random, and their subsequent survival depends on selection by the environment: only a few mutations survive. In innovation processes, mutations (i.e., innovations) are not generated at random but by intelligent people who try to select only the most promising innovation opportunities.

2. See Zerbe and Devily (1994) for a discussion of how to approximate the social rate.

Suboptimality in the selection of agricultural R&D projects

So far, we have focused on the "ideal" version of the selection process, assuming complete information and efficiency, so that the project with the highest ERR is always selected first. In reality, the selection of projects will be less than ideal, for two reasons: (1) there is incomplete information concerning the ERR, and (2) selection procedures involve arguments other than efficiency alone.

Assuming imperfect information and selection inefficiency, figure 4 depicts the rate-of-return distribution of a hypothetical, suboptimal selection of agricultural R&D projects.

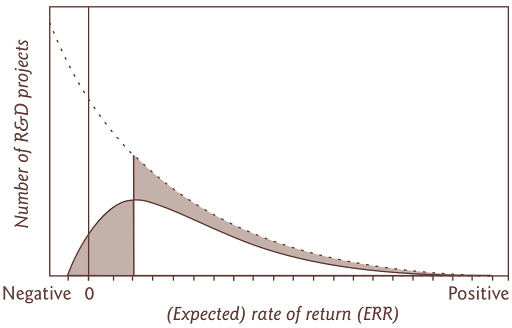

Figure 4: Hypothetical distribution of selected R&D projects under the assumption of limited selection rationality

In contrast to the optimal selection as depicted in figures 2 and 3 (which assumes a sharp cutoff point), the suboptimal ex ante selection can be expected to take the form of a normal distribution that is lopsided to the left. A considerable number of projects below the optimal cutoff rate are selected at the expense of projects above the optimal cutoff rate (the shaded areas in figure 4, which are equal in size). Although less than optimal, the distribution still reflects a considerable level of selection rationality, in that agricultural research projects with negative ERR are largely avoided.[3]

3. In the worst possible scenario, there is no selection rationality whatsoever, and R&D projects are selected completely at random (the "evolution" theory). In such a case, every possible R&D project has the same chance of being selected, and the overwhelming majority of selected R&D projects will have a negative ERR.

The model highlights two distinctive aspects of the investment problem:
1. determining the position and shape (relative to the ERR axis) of the set of agricultural R&D projects available for selection at any given point in time;
2. selecting the best possible projects from this set.

Since the exact position and shape of the set of agricultural R&D projects from which to choose are unknown ex ante, any statements concerning our under- or overinvestment in agricultural R&D are highly uncertain. The issue is further complicated by the suboptimality of the actual selection of agricultural R&D projects. However, Roseboom (2002a, 2002b) attempted to reconstruct and approximate the ex ante choice sets for both developed and developing countries by using a compilation of ex post rates of return for agricultural R&D projects, as collected by Alston et al. (2001). He found that
1. in relative terms, the ex ante choice set of profitable R&D projects (i.e., those exceeding the social rate) was significantly larger for developed than for developing countries circa 1981–85;
2. between the early 1960s and early 1980s, the ex ante choice sets for both developed and developing countries shifted to the right of the ERR scale.

These findings confirmed the hypothesis that the ex ante choice set of R&D projects is not static but varies between countries and through time. It makes sense to examine the factors that determine the position and shape of the ex ante choice set in more detail. But first we will discuss the factors that determine the level of suboptimality in project selection.

Factors affecting selection suboptimality

In their seminal book *Science under Scarcity*, Alston, Norton, and Pardey (1995) set out in detail the economic principles and methodologies for priority setting in agricultural research. Their message is simple and consistent with our ideal version of project selection: the project with the highest ERR should always be selected first.

In practice, however, expected rates of return are rarely calculated in selection procedures in the way suggested by these authors. Often, neither the required information, nor the necessary expertise are readily available. Nevertheless, some partial information concerning the possible costs and benefits of R&D projects is brought into the selection procedure, and projects are ranked in one way or another.

Even with incomplete information, very good projects can be separated from very bad projects with reasonable accuracy. The real selection problem comes with projects lying close to the cutoff rate for a given R&D budget. How can one distinguish between a project with an ERR that is one percent higher than the cutoff rate, and one with an ERR that is one percent lower than the cutoff rate? The standard error in most ERR calculations is such that these projects cannot be differentiated, and with incomplete information, these standard errors become even larger. This creates a considerable area, on both sides of the cutoff rate, in which the selection process is most sensitive to noneconomic arguments. If there is no strong indication that a particular project will be highly profitable or unprofitable, noneconomic criteria will become more important in determining the selection outcome. Therefore, the closer to the cutoff rate, the more influence noneconomic considerations acquire in the final selection of projects. Interestingly, it is also close to the cutoff rate that one tends to find the highest concentration of selected R&D projects.

Some suboptimality in the selection of agricultural R&D projects is unavoidable, although ideally it should be kept to a minimum. There is, however, a trade-off between better information (i.e., knowing the exact position and shape of the ex ante choice set) and the cost of obtaining such information. Hence, some error in the selection of agricultural R&D projects can be explained in purely economic terms (i.e., the cost of information). Such information costs may vary between research organizations, between countries, or through time. Information and experience accumulated through time may gradually reduce the costs of information and reduce the selection error.

Interestingly, several authors have suggested that distorted information may explain underinvestment in agricultural R&D. Oehmke (1986), for example, argued that the benefits of R&D are systematically underestimated in ex ante rate-of-return calculations. This leads to an overly pessimistic view of the ex ante choice set and therefore to systematic underinvestment in agricultural R&D. Fox (1985) argued exactly the opposite, suggesting that R&D costs are systematically underestimated in ex post rate-of-return calculations by ignoring the "deadweight" economic losses due to taxation. As a result, ex post rate-of-return estimates tend to give a consistently overoptimistic picture of the ex ante choice set and thus overestimate the underinvestment gap.

Even when full and accurate information can be assumed, the selection of R&D projects can be influenced by many other factors that shift it away from the economic optimum. Stakeholder participation and political lobbying, for example, can contribute positively by bringing more accurate and relevant information both to the selection process and to setting an R&D agenda. However, the outcome of this process may not be very balanced. De Janvry, Sadoulet, and Fafchamps (1989), for example, argued that, in a typical dual-economy setting, rich farmers skew the selection of R&D projects in their favor through their superior political lobbying capabilities. In such instances, transparent priority-setting procedures that can balance various political and economic interests are needed to enhance selection efficiency and reduce selection error (Roseboom, Diederen, and Kuyvenhoven 2003).

A false assumption in our economic selection model is that all agricultural R&D projects (or, for that matter, all government projects) are compared with each other at exactly the same time. In reality, budget allocation processes are structured such that information concerning investment opportunities in individual (R&D) projects is aggregated into larger portfolios of activities. Much detailed information is lost as a result. Moreover, budget allocations tend to be rather "sticky" (in that funds allocated one year to a large extent define those allocated the following year); this is particularly true at the aggregate level. In other words, the ability to respond quickly and flexibly to expanding or contracting R&D investment opportunities is limited.

Overall, one could argue that the selection error in developing countries is probably considerably larger than in developed countries, for the following reasons:

- information is less precise;
- selection procedures are less efficient and transparent;
- budget allocation mechanisms are less responsive;
- there is a lack of political will and organizational capacity in society.

Together, these factors provide a plausible explanation for the fact that developing countries seem to have, under the extreme assumption of perfect selection, a substantially larger underinvestment gap than developed countries (Roseboom 2002a, 2002b). This is the price that developing countries pay for the higher level of error and distortion in R&D project selection. The best way of reducing underinvestment in agricultural R&D is by better mastering the selection process and reducing selection error and distortions. The factors mentioned above form a good starting point for considering ways of reducing selection error.

Factors affecting the ex ante choice set

While the previous section focused on the factors that determine selection suboptimality, this section addresses those factors that determine the set of agricultural R&D projects available for selection (i.e., the ex ante choice set).

The following six factors play a role in defining the position of the ex ante choice set on an ERR scale:

- technology
- economies of scale
- industry structure
- R&D efficiency and effectiveness
- adoption rate
- risk and uncertainty

A technical ranking of all imaginable R&D projects considers only the technical merit of the proposed innovation relative to current technology and is usually expressed in terms of a reduction in production costs per unit output. This technical ranking is then multiplied by innovation-specific scale factors, which reflect the breadth and depth of the possible economic application of the innovation. This may change the original technical ranking quite substantially—very promising technical improvements can turn out to have low or negative expected rates of return because their potential application is limited. On the other hand, small technical improvements can have high expected rates of return because of their wide application.

The structure of an industry also plays an important part in shaping the ex ante choice set. Primary agriculture is a classic example of a very fragmented industry in which market forces generally fail when it comes to generating new technology. The benefits accruing to individual farmers from an invention are far too small to constitute much of an incentive for them to invest substantial sums in their own R&D. Joint action or government intervention is therefore needed to overcome this market failure. In less fragmented industries, the incentive to invest in one's own R&D is considerably higher. There is an extensive body of literature documenting the effect of industry structure on the incentives for individual companies to invest in R&D.

R&D efficiency and effectiveness determine the ultimate costs and benefits of any R&D activity. These two performance indicators are assumed to be roughly the same for projects within an organization, while varying between R&D organizations and (to an even greater extent) between countries. Weak R&D performance usually reflects weak organizational capabilities within a particular society. Idachaba (1998), for example, documented how the late and very erratic release of government funding places a major constraint on the performance of agricultural research organizations in Nigeria. Overstaffing is another phenomenon that often negatively affects the performance of agricultural research organizations in developing countries: once all salaries have been paid, there is little left for operating expenses or capital investment (Pardey et al. 1998).

If adoption is slow or incomplete, the potential benefits of an innovation may not be fully realized. For example, 70% of the target farmers may potentially grow a new maize variety, but past adoption rates indicate that only 50% will actually do so. The technical, ranked distribution of R&D projects must therefore be corrected, not only for scale, structure, and R&D efficiency and effectiveness, but also by a factor that reflects the adoption or diffusion rate of the proposed innovation. Low adoption rates are caused by weak institutions and high transaction costs—problems that are particularly prevalent in developing countries.

The way in which information concerning new technology is packaged and transferred to farmers, and how farmers assess the innovation relative to their own specific situation, are critical for the successful adoption of new technologies. However, farmers may be aware of new technology and be convinced of its superiority, but may still face other constraints, such as lack of capital or credit, lack of required inputs at a given place and time, land tenure issues, and seasonal labor shortages (Pinstrup-Andersen, 1982). Government policies targeting these constraints play an important role in improving rates of adoption and hence in shifting the agricultural R&D choice set further up the ERR scale.

Since research is an inherently risky and uncertain activity, it is at odds with the risk-averse nature of people. Hence, depending on how averse to risk they are, private individuals and companies will shy away from risky projects and will discount for the statistical variance of the ERR when ranking R&D projects. The risk-averse version of the choice set of possible R&D projects can therefore be thought of as positioned lower (i.e., further to the left) on the ERR scale than the risk-neutral version. However, this creates a divergence between the ex ante and ex post versions of the choice sets, with the latter more or less coinciding with the risk-neutral version.

Arrow and Lindner (1970) argued that in a typical public-investment situation, governments can safely ignore risk as long as the investment is small relative to national income. Given that this is true for most public agricultural R&D projects, risk aversion should not play a significant part in the selection of public agricultural R&D projects (Anderson 1991). In other words, public agricultural R&D projects with the same ERR, but differing in their relative risk (as reflected in the higher statistical variance of riskier projects), should be treated in the same way. The chance of a lower outcome in one project is compensated by the chance of a higher outcome in another. Despite this theoretical argument, public-research administrators probably show moderate risk aversion so that they can meet demands for short-term accountability with at least some positive results (Greig 1981).

However, risk and uncertainty are not static and may decline over time. R&D proposals initially turned down as being too risky may be selected later, when critical variables can be predicted more accurately. For example, experience in a certain research field may lead to increased confidence in research effectiveness over time.

The list of underlying factors presented above is not necessarily exhaustive: other factors may also play a role. Moreover, the relative importance of each of the six identified factors differs between research fields. Understanding which factors are the most important is critical when considering policies that could shift the choice set higher up the ERR scale.

Table 1 summarizes some of the government policies that could have a positive effect on each of the six factors, although several have effects that go far beyond R&D. These policies condition the extent to which R&D can contribute to the overall economy. In developing countries in particular, the profitability of R&D projects is often severely restricted by structural and institutional factors, such as infrastructure, education, and incomplete markets. One of the most important constraints is political instability, which disproportionately affects those investments, like R&D, which have a long time-horizon.

R&D can also be self-reinforcing in the sense that past R&D results and experiences can have a positive impact on (some of) the underlying factors shaping the current choice set of R&D projects. For example, gaining more experience in R&D increases the efficiency and effectiveness of R&D over time. Also, adoption of new technologies may proceed more easily once consumers and markets have become

Table 1: Policies that Could Help Expand the Ex Ante Choice Set of (Agricultural) R&D Projects

Factor	Policies that could have a positive effect on this factor
Technology	Investment in basic science, training of researchers, and improved access to knowledge
Economies of scale	Legislative and financial support for joint R&D activities in fragmented industries, supranational cooperation
Structure of the innovating industry	Effective anti-trust legislation to avoid monopolistic situations and patent legislation to provide incentives for private investment in R&D
R&D efficiency and effectiveness	Developing capacity to train researchers, improved management and organization of government research organizations
Adoption rate and speed	Markets, infrastructure, credit, education, etc.
Risk and uncertainty	Political stability; clear policies on intellectual property rights, ethical standards, and other regulatory measures; capacity to predict future developments (e.g., foresight studies, scenarios)

accustomed to rapid technical change. Risk and uncertainty may also be reduced by past R&D results. At the same time, however, there is a strong suggestion in the literature that the ultimate number of innovation opportunities (and profitable R&D projects) is limited and will eventually be exhausted. While this is true for specific lines of research, it is questionable at an aggregate level, since new lines of research open up all the time.

A somewhat puzzling dilemma is whether limited research capacity in developing countries constrains their ability to fully identify the ex ante choice set of potential R&D projects. Some minimum research capacity is undoubtedly necessary to identify new research opportunities, but the idea that additional research capacity will create its own profitable opportunities does not fit well with the present model.

Conclusions

The selection model presented in this briefing paper takes the underinvestment argument to extremes by assuming full information and selection rationality. The model is useful not because it is a good approximation of reality but because it provides a benchmark with which to compare reality. The benchmark is quite simple: the optimal level of investment in agricultural R&D lies at the point where all R&D projects with an ERR at or exceeding the social rate are being financed. In reality, the selection of R&D projects will never be perfect (from an efficiency point of view) because of imperfect information and distortions in the selection process. Since policymakers know from experience that project selection will always be imperfect, they tend to keep their investments safely below optimal levels. Every failed R&D project signals a potential "overshooting" of their target. Moreover, as we have argued earlier, selection efficiency tends to be lower in developing countries. This creates a stronger impression of overshooting the target and hence induces relatively larger underinvestment gaps compared to those in developed countries. Although it is unrealistic to expect to completely eliminate selection suboptimality (and hence underinvestment), improving the selection process would nevertheless help reduce underinvestment in agricultural R&D. There is a reason why investors in agricultural R&D continually insist on better strategic planning and priority setting: they want to see their investment used in the best possible way.

Another important insight provided by the model is that, irrespective of selection suboptimality, the choice sets of agricultural R&D projects differ between countries and through time: they are not fixed or static. It is therefore logical to focus on policies that help create more attractive (i.e., postioned higher on the ERR scale) agricultural R&D choice sets. Eventually, this will be the most effective way of attracting additional resources for agricultural R&D.

In summary, this briefing paper argues that additional resources could be pulled (rather than pushed) into agricultural R&D by focusing on (1) factors that enlarge the choice set of profitable agricultural R&D projects, and (2) factors that improve the selection of projects from that set.

About the author

Johannes Roseboom is a research officer at ISNAR and has extensive experience in agricultural research investment issues. This briefing paper is based on part III of his dissertation *Essays on Agricultural Research Investment* (Roseboom, 2002a). A more extensive version of part III will be published as an ISNAR Research Report titled "Optimizing investment in agricultural research, or the quest for prosperity" later this year.

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