A new perspective on underinvestment in agricultural R&D

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Abstract:

During the past 40 years, the returns to agricultural R&D have been on average in the range of 40-60% (Alston, *et al* 2000, Evenson 2001). Many agricultural economists see this high average as convincing evidence that there is significant underinvestment in public agricultural R&D (Ruttan 1980, Pinstrup-Andersen 2001).

This paper sheds new light on the underinvestment hypothesis by introducing a simple model of the selection of R&D projects and confronting it with the rate-of-return evidence accumulated over the years worldwide. The model assumes that the distribution of all possible R&D projects on an expected rate-of-return (ERR) scale declines asymptotically. Under the neoclassical conditions of full information and profit maximization, R&D project selection starts with the project with the highest ERR and continues until the budget is finished or the last project hits the social cutoff rate, whichever comes first. Hence the underinvestment gap can be defined as the difference between the ERR of the marginal R&D project (the actual cutoff rate) and the social cutoff rate. Only three variables need to be known to estimate the underinvestment gap: the social cutoff rate, the actual cutoff rate, and the slope coefficient. Taking less than full information and economic rationality into account, the paper discusses how the latter two can be derived from a sufficiently large and representative sample of ex-post rates of return on agricultural R&D.

Important findings of the model are:

- Not the *mean* but the *mode* of the ex-post rate-of-return distribution is the relevant variable for assessing underinvestment in agricultural R&D.
- Under the assumption of full information and profit maximization, developed countries could have invested about 40% more in public agricultural R&D and developing countries about 137% more. In terms of agricultural R&D intensity (i.e., R&D expenditures as a percentage of AgGDP), developed countries could have invested 2.8% rather than 2.0%, and developing countries 1.0% rather than 0.4% in 1981-85.
- Low investment in public agricultural R&D in developing countries is caused foremost by a relatively smaller portfolio of profitable R&D projects to choose from. Underinvestment certainly plays a role (the gap is bigger for developing countries), but it explains only a small part of the difference in agricultural R&D intensity between developed and developing countries.
- While efforts to reduce the underinvestment gap should continue (e.g., better priority setting and mobilization of political support), more emphasis should be placed on designing policies that help to shift (the portfolio of) R&D projects higher up on the ERR scale, even at the risk of increasing the underinvestment gap.

Key words: agricultural R&D, underinvestment, rate of return, research intensities

1. *Introduction*

Starting with a study on hybrid corn by Griliches (1958), rate-of-return studies have become standard practice in documenting the economic impact of agricultural R&D. Although the estimated ex post rates vary quite substantially, the average tends to range in the order of 40-60% (Alston *et al.* 2000, Evenson 2001). Though many have questioned the accuracy of these rates and expressed doubt about as to how representative the selected projects are, a widely shared belief is that the estimated rates are robust enough to accommodate such criticisms and still be in a range that is substantially above the social cutoff rate. Based on this evidence, Ruttan (1980) argued that there is serious underinvestment in public agricultural R&D. This argument has become a widely accepted opinion (if not fact) among agricultural economists. Therefore, any slowdown in the growth or, even worse, any contraction of public agricultural R&D expenditures is reason for serious concern.

But what do we actually know about this underinvestment? How real is it? Is it higher in developing countries than in developed countries? Is it higher for some types of research than others? And, how much more should have been invested in agricultural R&D? In order to answer these questions, the underinvestment argument needs to be defined more clearly. This paper attempts to do so by introducing a simple model that represents the ideal, economic version of the selection of R&D projects. The outcome in real life is, of course, different because the assumptions of full information and strict rational maximizing behavior only hold partially. Nevertheless, this paper argues that in retrospect it should still be possible to detect the economic forces that determine the selection.

The structure of this paper is as follows. Section 2 starts with a brief introduction of the model and discusses a new way of interpreting a representative sample of ex post rates of return on agricultural R&D. Section 3 focuses on the factors that determine the characteristics of the portfolio of R&D projects to choose from. The available statistical evidence and its interpretation are presented in section 4, while in section 5 the characteristics derived from the rate-of-return sample are linked with reported agricultural R&D investment levels. Having determined the order of magnitude of the investment gap, section 6 assesses the various possible explanations of why the investment gap exists. Section 7 summarizes the main conclusions.

2. *An economic model of the selection of R&D projects*

In a strict formal priority setting exercise R&D projects are ranked at the hand of their expected rate of return (ERR). This ERR is the internal rate of return (IRR) that equalizes the costs of an R&D project with the benefits resulting from it:

$$[1] \qquad \sum_{t=0}^{t=n} C_t(\hat{IRR})^{-t} = \sum_{t=0}^{t=n} B_t(\hat{IRR})^{-t}$$

where C_t and B_t represent the (expected) R&D costs and benefits in year t, and n the number of years between the start of the R&D project and the moment that the benefit stream is expected to end.

Not only n differs from project to project, but also the cost and benefit streams themselves differ in length and shape. Some R&D projects take only one year to complete, while others take 10 years or more (e.g., plant breeding) before a benefit stream emerges. Some technologies are adopted rapidly and widely, while others are adopted slowly and limited. Assumptions have to be made about all such aspects to estimate the ERR.

The number of possible R&D projects can be assumed to increase exponentially going from high to low ERRs, creating an exponential curve (figure 1). Under the assumption of rational economic behavior and full information, the selection of R&D projects for implementation starts with the project with the highest ERR and continues with the next highest until the R&D budget has been exhausted or the ERR on the last (i.e., marginal) R&D project approaches the social cutoff rate,

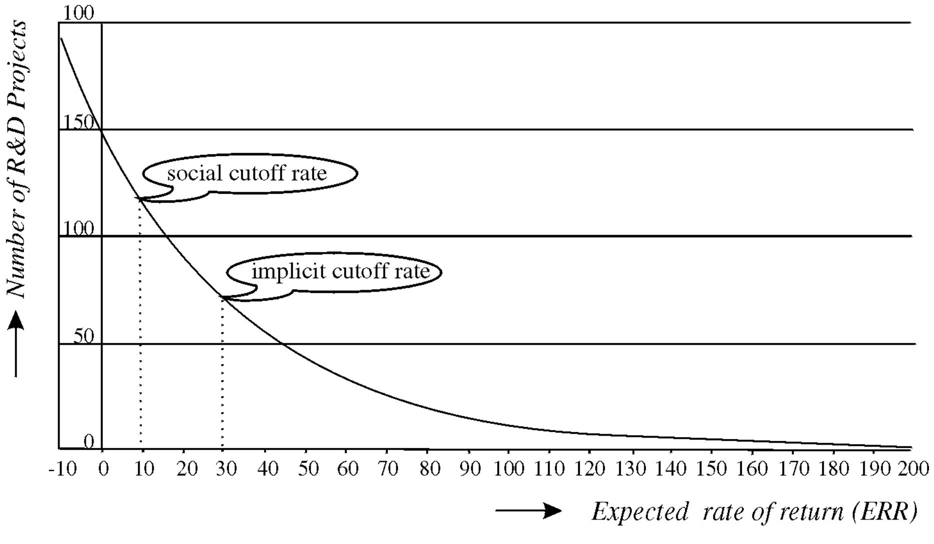


Figure 1: *A ranked distribution of R&D projects*

whichever comes first. When the highest ERR in the ranking does not exceed the social cutoff rate, no R&D projects should be implemented at all.

In a situation of abundant funding (i.e., where every project with an ERR equal to or higher than the social cutoff rate will be financed), the peak or mode of the ranked project distribution can be expected to be at the social cutoff rate. In a tight funding situation, however, the cutoff point of research proposals takes place before the social cutoff rate is reached.

The postulated distribution of R&D projects on an ERR scale can be thought of as taking the following semi-log form:

[2]
$$Y = e^{\beta_0} e^{\beta_1 X}$$

where Y stands for the number of R&D projects and X for the ERR. The coefficient β_1 has to be negative in order to get an asymptotic curve, as shown in figure 1. The closer the slope coefficient is to zero, the flatter the ranked distribution.

The accumulated number of R&D projects can be approximated by the following integral:

[3]
$$Y_r = \int_r^{\infty} e^{\beta_0} e^{\beta_1 X} dx$$

where Y_r stands for the number of R&D projects with a rate of return of r and higher.

The relative under- or overinvestment in (agricultural) R&D as a percentage of the original investment level can be estimated as follows:

[4]
$$\left[\frac{\int_s^{\infty} e^{\beta_0} e^{\beta_1 X} dx}{\int_r^{\infty} e^{\beta_0} e^{\beta_1 X} dx} - 1 \right] \times 100 = \left[\frac{\int_s^{\infty} e^{\beta_1 X} dx}{\int_r^{\infty} e^{\beta_1 X} dx} - 1 \right] \times 100 = (e^{\beta_1 \Delta X} - 1) \times 100$$

where s is the social cutoff rate and r the implicit cutoff rate and where X represents the difference between r and s.

Based on this simple stylized model, underinvestment in R&D can be captured in the following two postulations:

(1) Assuming full information and a strict economic selection of R&D projects, under-investment in R&D manifests itself in a cutoff rate that is higher than the social cutoff rate.

(2) The size of the R&D underinvestment gap depends on three variables: (a) the relevant social cutoff rate, (b) the actual cutoff rate, and (c) the slope of the ranked distribution curve.

To answer the questions whether there is underinvestment in R&D or not, and, if so, how much, variables *b* and *c* need to be estimated and *a* set. In the literature one can find ample discussion on the appropriate definition of the social cutoff rate and its corresponding value (see for example Zerbe and Devily [1994]). Here we have settled on using a social cutoff rate of 7% real (that is, net of inflation) for developed countries and 12% real for developing countries. The more challenging task is to estimate variables *b* and *c*.

In the real world, selection committees usually do not rank R&D projects on the basis of ERRs, nor do they have a concrete idea about the cutoff rate that they implicitly apply. However, the selection criteria actually used tend to underpin at least some economic rationale. Since the selection is less than economically optimal, a number of R&D projects with ERRs less than the "optimal" cutoff rate will be selected at the expense of R&D projects with an ERR to or above the "optimal" cutoff rate. This results in an ex ante ranked distribution of R&D projects that takes the form of a bell-shaped distribution, although lopsided to the left (figure 2).

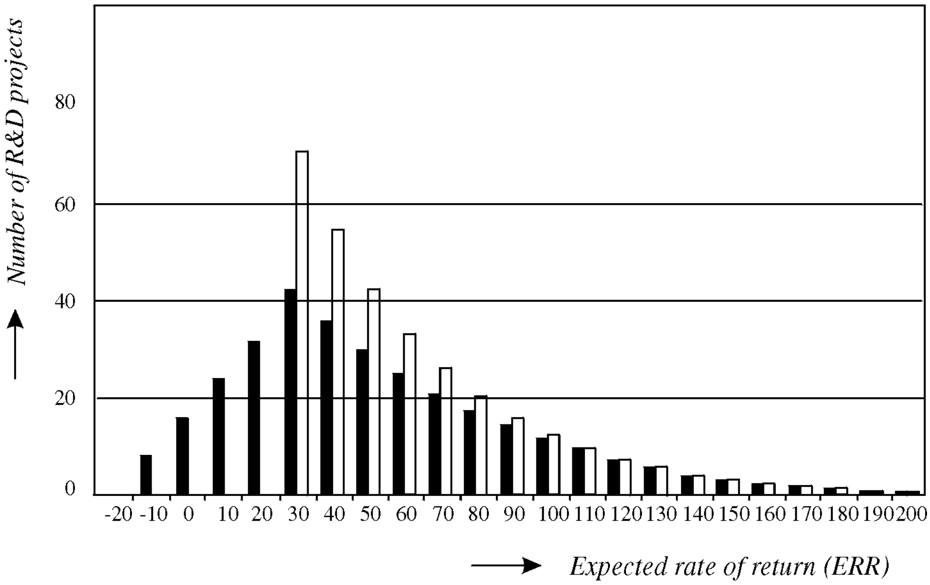


Figure 2: *The optimal versus suboptimal selection of R&D projects*

A critical assumption made here is that the modes of the *optimal* and *suboptimal* distributions should more or less coincide. At first, this may seem a rather bold assumption, but the opposite assumption, namely that the two modes significantly differ, is considerably more unlikely. Such an outcome is only possible when economic rationality in the selection of R&D projects is severely violated. Assuming only a moderate level of selection inefficiency, the two modes should roughly fall together.

The next step is to link the ex ante distribution with the ex post distribution. The two should be roughly identical if the following assumptions hold: (1) the differences between expected and actual rates of return of R&D projects are only stochastic and not systematic; and (2) the outcome distributions of the ERRs are more or less symmetric. This latter assumption clearly does not hold when the success of an R&D project is considered discrete – it is either a full success or a complete failure. Although a common metaphor, it is more realistic to assume that the success of R&D (especially biological R&D) is relative rather than discrete and, hence, creates a continuous statistical distribution. Given the various parameters that enter an ERR calculation, each with its own probability distribution, the overall probability distribution of the ERR of an R&D project or program is not something that can be calculated easily. This is particularly true when the relationship between parameters and benefits is nonlinear. In such an instance a Monte Carlo simulation can be used to estimate measures of the central tendency (e.g., mean or mode) and dispersion (e.g., variance and coefficient of variation) of the outcome distribution (Sprow 1967). To my knowledge, only a few studies (Greig 1979; Anderson 1991) have actually used this approach in an agricultural R&D setting. They reported probability distributions that are only slightly skewed.

Based on a rather strict, neoclassical interpretation of the R&D priority-setting process (i.e., that R&D investments are based on full information about profit opportunities and rational priority setting), the following postulate is proposed:

(3) Assuming that the evaluated R&D projects are selected at random and their ex post rates of return differ only stochastically and not systematically from the expected rates of return, the

mode of the distribution of the ex post rates conveys some rough indication of the implicit cutoff rate used in the ex ante optimal selection procedure.

In order to distill information on the *slope* of the ex ante distribution from a sample of ex post rates of return some strict assumptions have to be made. Figure 3 sketches the problem that needs to be tackled. Due to suboptimal selection, some of the projects with an ERR higher than the cutoff rate are not selected, while projects with an ERR lower than the cutoff rate are. It is assumed that all projects cost the same. If the selection were optimal, only R&D projects at or above the cutoff rate would have been selected. In order to reconstruct the ex ante *optimal* distribution, the right-hand side of the distribution has to be topped up with the number of R&D projects below the cutoff rate.

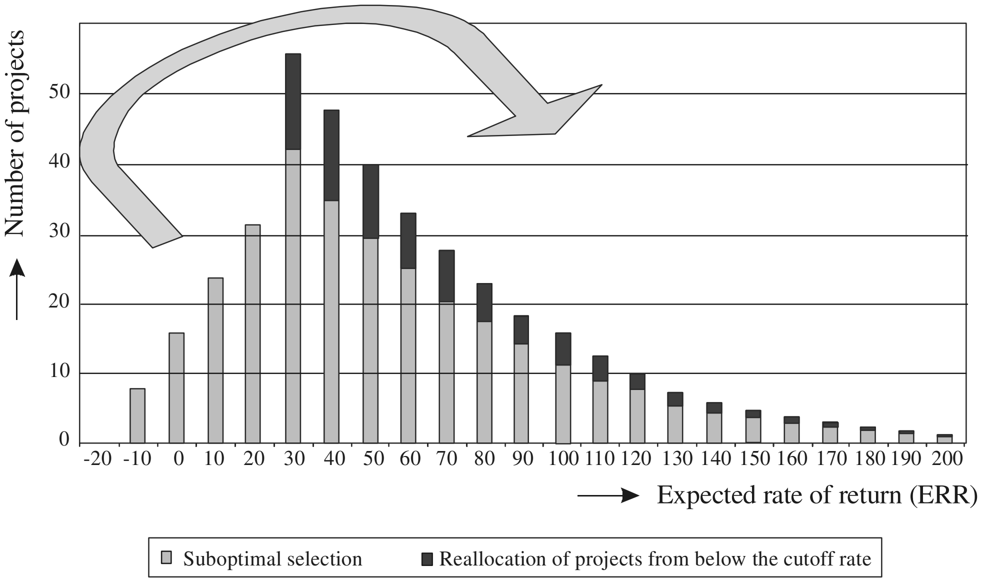


Figure 3: *Reconstruction of the optimal selection of R&D projects*

Of the various options available, distributing the suboptimal R&D projects proportionally seems to give a reasonable approximation and has the practical advantage that the adjusted and unadjusted right-hand side of the distribution has the same slope coefficient. However, a proportional distribution implies that the chance of not being selected is the same for all R&D projects above the cutoff rate. A more realistic assumption is that R&D projects close to the cutoff rate have a higher chance of not being selected than projects with higher ERRs. Such a differential in chance would lead to a steeper optimal slope and, hence, a bigger underinvestment gap. However, we lack empirical evidence on this chance distribution and have therefore adopted the second-best solution, namely, assuming equal chance and proportional distribution. Hence, the following postulate:

> *(4) The slope of the right-hand side of the ex post distribution of R&D projects is a reasonable but somewhat lower estimate of the slope of the optimal ex ante distribution.*

3. *The position of the ranked distribution of R&D projects on the ERR scale*

The model presented in the previous section suggests that the position of the ranked distribution of possible R&D projects on the ERR scale ultimately defines how much can be invested profitably in R&D. This section focuses on and analyzes the underlying factors that shape the *economic* ranking of R&D projects and, hence, the relative position of the ranked distribution on the ERR scale.

The position of the portfolio of possible R&D projects on the ERR scale can be thought of as depending on the following six interacting factors: (a) technology; (b) scale; (c) the structure of the industry; (d) R&D efficiency and effectiveness; (e) adoption rate; and (f) risk and uncertainty.

The *technical* ranked distribution of all imaginable R&D projects is based only on the technical merits of the imagined innovations relative to the technology in place and can be expressed in terms of a reduction in production costs per unit output. This technical ranked distribution is then multiplied with innovation-specific *scale* factors reflecting market potential or, in the case of public R&D, reflecting potential social impact. This may change the original technical ranking quite substantially – promising technical improvements can turn out to have low or negative ERRs because their potential use is limited, while small technical improvements can turn out to have high ERRs because of their wide application.

The *structure of an industry* also plays an important role in shaping the portfolio of possible R&D projects. Primary agriculture is a classic example of a very fragmented industry where market failure prevails when it comes to generating new technology. The benefits individual farmers can appropriate from an invention are far too small to constitute much of an incentive to invest substantial sums in their own R&D. Joint action or government intervention is needed to overcome this market failure. In industries that are more concentrated the incentives to invest in their own research is considerably higher.

R&D efficiency and effectiveness determine the ultimate costs and success of the R&D activity undertaken. These two performance indicators are assumed to be roughly the same for projects within an organization, but different between R&D organizations and even more so between countries. Weak R&D performance usually reflects weak organizational capability in a society in general. 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. After all salaries have been paid, hardly any budget is left for operating expenses or capital investments (Pardey, Roseboom, Beintema, and Chan-Kang 1998).

Because of incomplete or slow *adoption*, not all potential benefits of an innovation may materialize. For example, a new maize variety could potentially be grown by 70% of the farmers, but past adoption rates indicate that only half of them will actually grow it. Hence the technical, ranked distribution of R&D projects must not only be corrected 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 can be thought of as being caused by weak institutions and high transaction costs – problems that are particularly prevalent in developing countries.

Crucial to the adoption of new technology is how information about the new technology is packaged and transferred to farmers and how farmers assess the new technology in their own specific situation. Farmers may know about the new technology and be convinced about its superiority, but they may face other constraints, such as lack of capital or credit, lack of required inputs at given place and time, land tenure issues, and seasonal labor shortages, to name just a few as listed by Pinstrup-Andersen (1982). Government policies targeting these constraints play an important role in improving rates of adoption and, hence, shifting the distribution of R&D projects to the right on the ERR scale.

Being an inherently *risky and uncertain* activity, research is at odds with the risk-averse nature of humanity. Hence, private individuals and companies will, depending on how averse to risk they are, shy away from risky projects and discount for statistical variance of the ERR when ranking R&D projects. Therefore, the risk-averse version of the ranked distribution of R&D projects can be thought of as positioned lower on the ERR scale than the risk-neutral version. This creates a divergence between the ex ante and ex post rate-of-return distributions, as the latter will more or less coincide with the risk-neutral version.

Arrow and Lindner (1970, 1972) argue 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 investments, risk aversion should not play much of a role in the selection of public agricultural R&D projects or programs (Anderson 1991). In other words, public agricultural R&D projects or programs with the same ERR, but with one being riskier than the other (reflected by a higher statistical variance), should be treated the same. The chance of a lower outcome is compensated by the chance of a higher outcome. Despite this theoretical argument, public-research administrators most likely act moderately risk-averse, so that demands for short-term accountability can be answered by at least some positive results (Greig 1981).

Risk and uncertainty are not static and may decline over time. R&D proposals that are initially turned down as being too risky may be selected at a later stage when critical variables can be predicted more accurately. For example, experience in a certain research field may increase the confidence in research effectiveness over time.

The six underlying factors presented here are not necessarily exhaustive. Other factors may play a role as well. Moreover, the relative importance of each of the six factors differs across research fields. Market structure, for example, does not play much of a role when considering public (agricultural) R&D. For other fields of research, however, this may constitute a highly relevant factor that affects the ERR of R&D projects and hence shape up the available R&D opportunities. Understanding which factors are the most critical is important when considering policies that could shift the portfolio of possible R&D projects higher up on the ERR scale.

Table 1 summarizes some of the government policies that could affect each of the six factors positively. Several of these policies are far broader than just R&D policy. 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 constrained by structural and institutional factors, such as infrastructure, education, and incomplete markets. One of the most constraining factors, however, is that of political instability—it disproportionately affects investments with a long-time horizon, like R&D.

Table 1: *Policies that could affect R&D opportunities positively*

Factors affecting the ranked distribution	*Policies that could affect the position of the ranked distribution positively*
Technology	Investment in basic science, training of researchers, improved access to knowledge
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 IPR, ethical standards, and other regulatory measures; capacity to predict future developments (e.g. foresight studies, scenarios)

R&D can also be self-enforcing in the sense that past R&D results and experiences may have a positive influence on (some of) the underlying factors that shape up the portfolio of possible R&D projects today. For example, becoming more experienced in conducting R&D increases the efficiency and effectiveness of R&D over time, and technology adoption may become easier once consumers and markets have become accustomed to rapid technical change. Risk and uncertainty may also be reduced by past R&D results.

The ranking of industries by R&D intensity stands out as rather stable in cross-country comparisons among developed countries (Freeman and Soete 1999). Despite substantially lower levels of investment in R&D in general, industries in developing countries also comply to roughly the same ranking (Roseboom 1999). So, across all countries, food-processing industries have relatively low R&D intensities, while pharmaceutical industries have relatively high ones. This finding could be explained by assuming that some of the underlying factors are more industry-specific, such as technology base and industry structure, while other factors are more country-specific, such as scale, R&D efficiency and effectiveness, and technology adoption rates. Risk and uncertainty could fit in either category. Explanations for differences in agricultural R&D intensities across countries should be sought among the more country-specific factors.

This characterization of the ranked distribution of R&D projects provides a rough outline of the factors that shape the portfolio of innovation opportunities. Depending on the specific industry and country, a further detailing of these factors should provide a better understanding of the innovation opportunities within reach, as well as what could be done to enhance them.

4. *Empirical evidence*

Rates of return on public agricultural R&D investments vary widely from negative to positive rates of 100% and more. On average, however, the reported rates range between 40% and 60% (Alston *et al.* 2000). In the literature, this high average has been used frequently as an indication of underinvestment in agricultural R&D (Ruttan 1980, Pinstrup-Anderson 2001). The argument made here is that the *mode* of the ex post rate-of-return results provides substantially more information about relative underinvestment in agricultural R&D than the *mean*. Hence, it is necessary to give a new interpretation to the reported rate-of-return results.

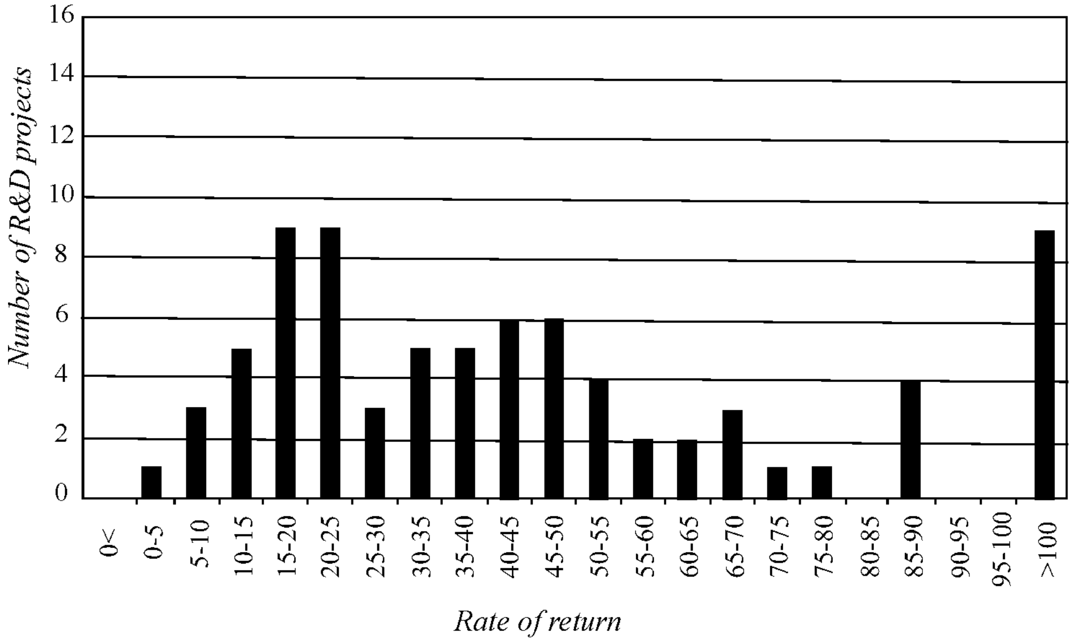
The most recent compilation of rates of return to agricultural R&D has been published by IFPRI (Alston *et al.* 2000). The focus of the IFPRI study, which is a meta-analysis of more than 1,800 agricultural R&D rate-of-return calculations, is to understand differences in rate-of-return results due to differences in methods, research focus, location, time, etc. For the purposes of the current study, however, a large number of the rate-of-return observations had to be eliminated, for reasons of comparability. For example, all nominal (rather than real) rates of return were eliminated as well as all rates of return pertaining to “all agricultural R&D,” “crop & livestock R&D,” or “all crop R&D.” Such R&D programs are far too aggregate to provide meaningful information about the marginal R&D project. Even after this correction, the set of rate-of-return results is still somewhat biased towards research programs rather than discrete research projects. The latter would be preferred in order to get as close a correspondence with the ex ante choice situation as possible.

Most rate-of-return studies provide multiple rates for the same R&D project or program, depending on the assumptions made, such as the time lag between R&D investment and impact. The analysis in this paper requires only one observation per project or program, so multiple observations had to be reduced to only one. Since there is not yet a solid theoretical basis for preferring one method to the other, an average rate was calculated for each research project. All in all, the more than 1,800 observations in the IFPRI study, boiled down to only 201 useful rate-of-return observations, of which 78 pertain to developed countries (mainly the USA) and 123 to developing countries. It is assumed that these 201 rate-of-return observations represent a reasonable sample of all the agricultural R&D projects that have been undertaken worldwide. Although R&D projects with low or negative rates of return are probably under-represented in the sample, this has fairly little effect on the two parameters that we want to estimate: the implicit cutoff rate and the slope coefficient. Each observation is given the same weight, which implies that each R&D project is assumed to have cost the same.

Figure 4 plots the distribution of ex post rates of return for both developed and developing countries. As can be seen, the mode for developed countries (estimated at a rate of return of 20%) stands out more clearly than the mode for developing countries (estimated at roughly 40%). Apparently, the assumption that the selection of R&D projects took place under more or less the same budget constraints (i.e., the same cutoff rate) and with more or less similar innovation opportunities holds less well for the developing countries as a group. This is confirmed by the quite different region-specific distributions as reported in tables 2, 3 and 4.

Table 2 provides more detailed and differentiated information about the characteristics of the various rate-of-return distributions. The differentiation between developing regions is somewhat speculative because of the rather small number of observations. Still, the distributions follow the expected pattern quite well. In all cases, the distribution is lopsided to the left with a median lower than the mean, and an *estimated* mode lower than the median. The share of observations lower than the mode ranges between 20% and 40%. When the distribution is perfectly representative (which unfortunately is not the case), this share would give an objective indication of selection performance.

The current sample includes a few very high rates of return (the highest is 855%), which in some instances causes rather high standard deviations and means that are biased upwards. Although one does not want to exclude very high rates of return a priori (although some healthy skepticism is warranted), statistically one expects them to be rare. However, the rate-of-return sample may not only have a blind spot for failed R&D projects, it may also be biased toward the extreme success cases. Very successful R&D projects just have a higher chance of being selected for an ex post evaluation.


(a) developed countries - 78 observations

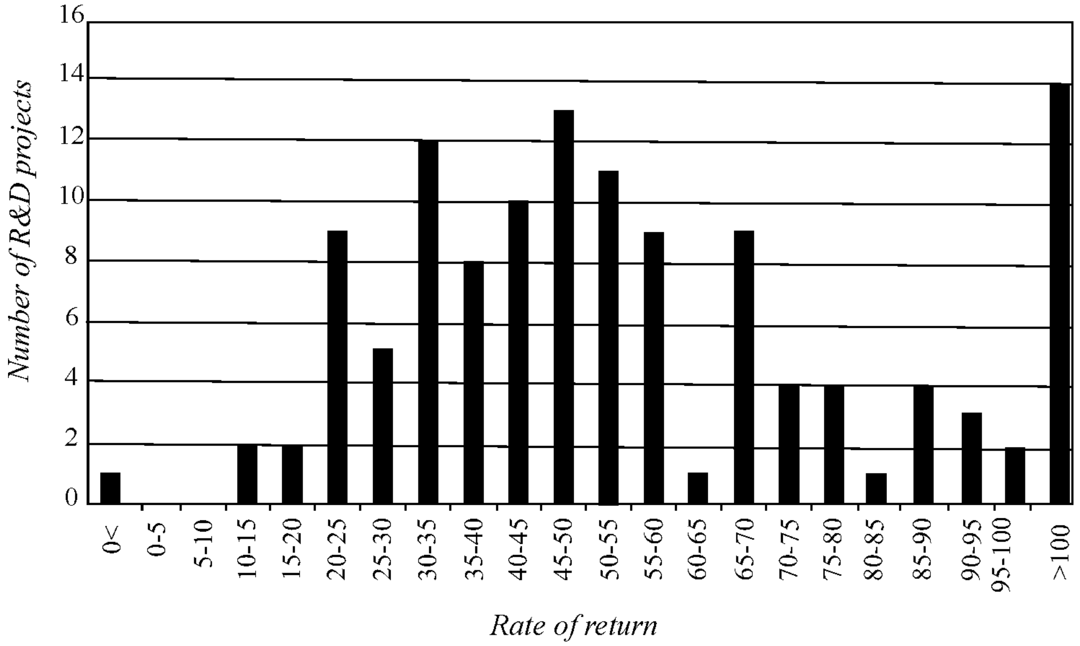

(b) developing countries - 124 observations

Figure 4: *Ranked distribution of ex post rate-of-return results*

Table 2: *Characteristics of the various rate-of-return distributions*

	Number of estimates	Rate of return				
		Estimated mode	Median	Mean	Standard deviation	% obs. < mode
	(count)	*(percentage)*				
Developed countries	78	20.0	38.8	65.8	119.7	23.1
Developing countries	123	40.0	50.0	58.9	37.9	31.7
Africa	25	30.0	36.1	46.4	27.2	20.0
Asia and Pacific	38	45.0	56.2	77.1	51.7	21.1
Latin America and Caribbean	56	40.0	47.9	51.9	26.7	36.4
Developed countries, 1985 ≤	31	20.0	41.3	79.6	152.6	22.6
Developed countries, >1985	47	20.0	34.0	56.7	92.6	23.4
Developing countries, 1985 ≤	33	40.0	47.8	55.3	32.3	39.4
Developing countries, >1985	90	40.0	51.4	60.3	39.9	28.9

Note: The grouping per time period has been based on the date of publication.

To estimate the underinvestment gap it is not only relevant to know the implicit cutoff rate and the social cutoff rate, but also the slope coefficient β_1. The approach taken here is to estimate β_1 by regressing rate-of-return observations on the right-hand side (those above the cutoff rate) of the ex post *cumulated* ranked distribution. Rates of return higher than 100% were excluded in order to eliminate their distorting effect on the estimation of the slope coefficient. As shown in table 3, this leads to a substantially better statistical fit of the exponential curve.

Varying the estimated mode or implicit cutoff rate with five percentage points for the developed countries and 10 percentage points for the developing countries affects the slope coefficient only marginally. Splitting the dataset into two time periods did not yield radically different slope coefficients either, nor did it suggest a notable change in the cutoff rate over time. However, the breakdown of developing countries by region led to a differentiation in implicit cutoff rates as well as slope coefficients. Given the relative small number of observations, these latter results are statistically not very robust. Nevertheless, it partially explains why we did not find a very clear mode for the developing countries as a group.

With estimates for the implicit cutoff rates as well as the slope coefficients and the social cutoff rate set at 7% for developed countries and 12% for developing countries, the underinvestment gaps can now be calculated using equation 4. The results of these calculations are presented in table 4 and suggest a considerably bigger underinvestment gap for developing countries (137%) than for developed countries (40%).

Table 3: *Regression results for estimating slope coefficient* β_1

	β_0	*t-statistic*	β_1	*t-statistic*	R^2
Developed countries – cutoff rate 20%					
All rates of return ≥ 20%	3.5859	43.45	-0.0054	-10.19	0.642
All rates of return ≥ 20% and <100%	4.6193	242.54	-0.0257	-66.68	0.989
All rates of return ≥ 15% and <100%	4.6340	315.62	-0.0259	-81.51	0.991
All rates of return ≥ 25% and <100%	4.6525	176.98	-0.0262	-53.38	0.986
All rates of return ≥ 20% and <100%, ≤ 1985	3.7143	51.51	-0.0242	-15.98	0.938
All rates of return ≥ 20% and <100%, >1985	4.1117	188.13	-0.0264	-61.08	0.992
Developing countries – cutoff rate 40%					
All rates of return ≥ 40%	5.1689	81.98	-0.0233	-30.34	0.918
All rates of return ≥ 40% and <100%	5.6659	264.60	-0.0308	-90.71	0.992
All rates of return ≥ 30% and <100%	5.6091	377.08	-0.0300	-116.53	0.993
All rates of return ≥ 50% and <100%	5.5628	196.02	-0.0295	-71.42	0.991
All rates of return ≥ 40% and <100%, ≤ 1985	4.3305	52.27	-0.0313	-25.20	0.975
All rates of return ≥ 40% and <100%, >1985	5.3658	176.03	-0.0305	-61.74	0.987
Africa: all rates of return ≥ 30% and <100%	3.9918	52.87	-0.0349	-23.34	0.971
Asia: all rates of return ≥ 45% and <100%	3.9940	62.36	-0.0162	-17.09	0.939
LAC: all rates of return ≥ 40% and <100%	5.4419	80.66	-0.0442	-40.73	0.982

Differentiating the sample in studies from before and after 1985 hardly affects these results. Given the rather approximate nature of the identified mode, extreme values for the mode were adopted, which resulted in lower and upper bounds of the underinvestment gaps. Not surprisingly, the underinvestment gap is quite sensitive to the estimation of the mode. Grouping the rates of return of developing countries by region yields quite a bit of variation in both the cutoff rate and the slope coefficient and suggests that underinvestment in agricultural R&D has been particularly high in Latin America.

While there is considerable room for improvement in the statistical data used in the present analysis (both in coverage as well as the quality of the rate-of-return methods used), the model cuts quite nicely through what looked like a Gordian knot. It shows that the high *means* of the rate-of-return distributions as such are no evidence of underinvestment in R&D, nor are they indicative of the size of the underinvestment gap. The approximated *modes* of the rate-of-return distributions are a substantially better indicator of underinvestment.

Table 4: *Estimations of the underinvestment gap*

	Cutoff rate	*Slope coefficient* β_1	*Underinvestment gap*
Developed countries (social cutoff rate 7%)			
Baseline	20%	-0.0257	39.7%
Rates of return ≤ 1985	20%	-0.0242	37.0%
Rates of return >1985	20%	-0.0264	41.0%
5% points lower cutoff rate	15%	-0.0259	23.1%
5% points higher cutoff rate	25%	-0.0262	60.4%
Developing countries (social cutoff rate 12%)			
Baseline	40%	-0.0308	136.9%
Rates of return ≤ 1985	40%	-0.0313	139.9%
Rates of return >1985	40%	-0.0305	134.8%
10% points lower cutoff rate	30%	-0.0300	71.6%
10% points higher cutoff rate	50%	-0.0295	206.3%
Africa	30%	-0.0349	87.3%
Asia	45%	-0.0162	70.3%
Latin America	40%	-0.0442	244.5%

5. *R&D opportunity curve*

In the previous sections agricultural R&D investments have been characterized without any reference to the actual amount invested. In this section the analysis will be taken a step further by linking the characteristics of the reconstructed ex ante distribution of agricultural R&D projects (i.e., the implicit cutoff rate and slope coefficient β_1) with past agricultural R&D investment levels as reported by Anderson, Pardey, and Roseboom (1994). By accumulating the ranked distribution, a third dimension can be added to the picture, namely, that of R&D expenditure or intensity. The resulting *R&D opportunity curves* provide a comprehensive way of simultaneously illustrating the differences in R&D opportunities and underinvestment between developed and developing countries (figure 5).

In retrospect, the optimal level of investment in agricultural R&D for developed countries can be estimated at $6.7 billion per annum rather than the actual $4.8 billion spent, by bringing the cutoff rate down from 20% to 7%.[1] For developing countries the difference is substantially larger – rather than the actual $4.4 billion, $10.4 billion could have been spent before reaching the social cutoff rate of 12% (figure 5a). In relative terms, however, the developed countries clearly stand out as having a

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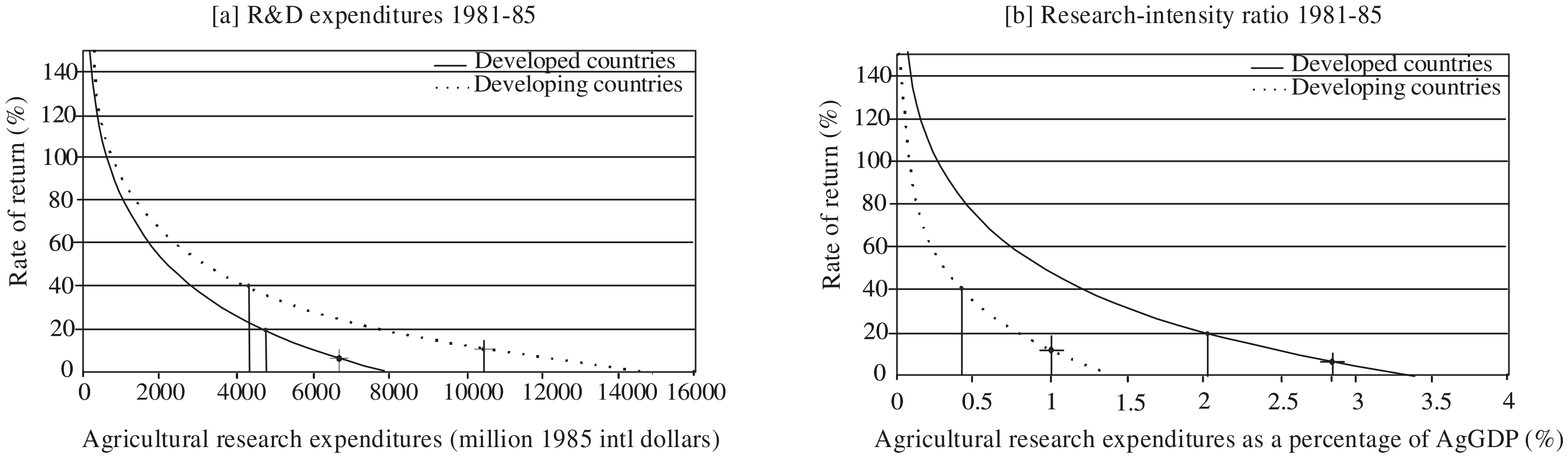
[1] The expenditure data reported here are expressed in constant 1985 PPP dollars.



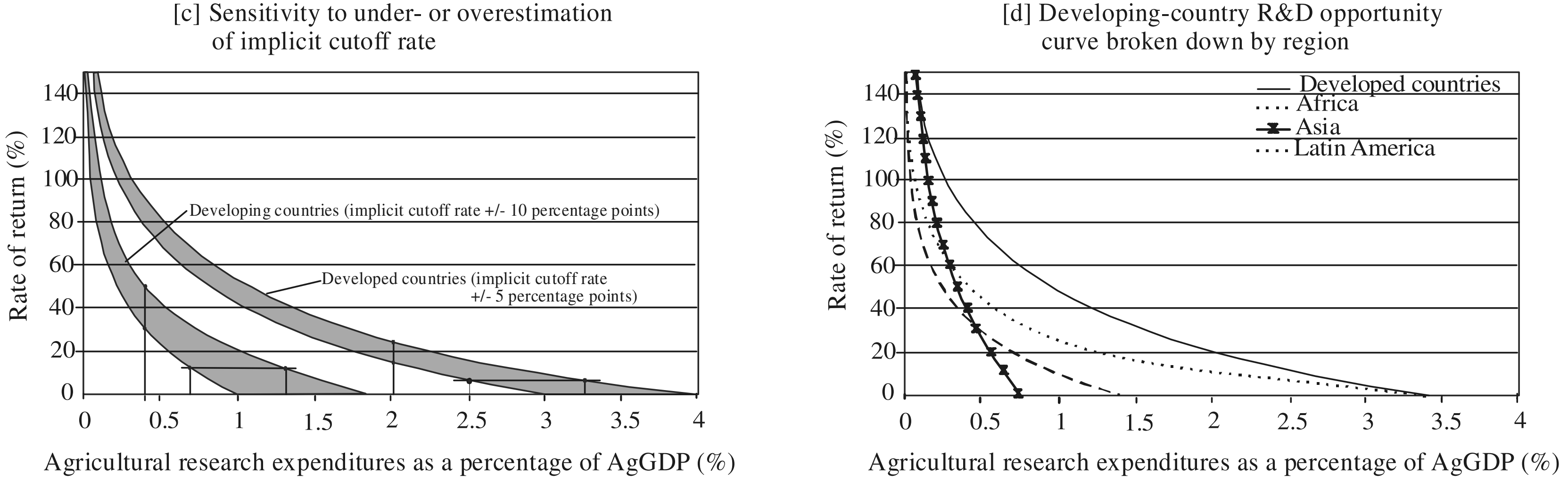


Figure 5: *R&D opportunity curves*

far larger portfolio of profitable agricultural R&D investment opportunities than the developing countries have. Their optimal R&D intensity (i.e., public agricultural research expenditures as a percentage of AgGDP) stands at 2.8%, compared to 1.0% for developing countries (figure 5b).

A differentiation of the R&D opportunity curve for developing countries by regions is presented in figure 5c. Although the actual R&D intensity for all three regions clusters around 0.5%, their estimated optimal R&D intensity ratios differ quite significantly: 0.9% for Africa; 0.6% for Asia; and 2.0% for Latin America. The robustness of these latter estimates is rather weak given the small number of rate-of-return observations per region. Nevertheless, it illustrates how, with sufficiently good rate-of-return data, some far-reaching conclusions regarding underinvestment in agricultural R&D could be derived.

In figure 5d, the R&D opportunity curves have been plotted for two different time periods. The results of the rate-of-return studies published in and before 1985 have been related to the expenditure level of 1961-65, while those published after 1985 are related to the expenditure level of 1981-85. The figure shows how, for both developed and developing countries, the R&D opportunity curve has shifted outward. If the R&D opportunity curve had not changed, the increase in R&D spending would have reduced the implicit cut-off rate and, hence, the underinvestment gap. For developing countries, this would have brought the cut-off rate close to 25%, while for developed countries the cut-off rate would have dropped below zero.

An implicit assumption frequently made in the literature as well as in policy advice is that the R&D opportunity curve is the same across countries and over time. For example, the recommendation made by the World Bank that developing countries should invest 2% of their AgGDP in agricultural R&D by 1990 (World Bank 1981) is based on this assumption. The developed-country investment level of the early 1980s is taken as the target, and assuming that all countries are on the same curve, closing the underinvestment gap is a matter of moving along a fixed curve. If the advice had been followed, developing countries would have overinvested in agricultural R&D by quite a margin. The results of the current analysis suggests that for 1981-85 the optimal investment level for developing countries was about 1.0% (rather than the actual 0.4%) and that for developed countries, it was about 2.8% (rather than the actual 2.0%). It is important to realize that even at modest investment levels, overinvestment may very well take place if profitable innovation opportunities are scarce or nonexistent. Lack of economies of scale, for example, may place many innovation opportunities out of reach economically for small production areas or countries. More generally, institutional constraints such as non-existent or poorly functioning markets may hold back innovation opportunities and, hence, the level of R&D investment.

Developed countries invest far more in agricultural R&D per unit value-added than developing countries for three reasons: (1) in relative terms their portfolio of profitable R&D projects is far larger; (2) their social cutoff rate or optimal cutoff rate is lower (7% against 12% in developing countries); and (3) their estimated (implicit) cutoff rate is substantially lower (20% against 40% in developing countries). Moreover, their portfolio of profitable R&D projects has grown considerably faster than their AgGDP, which has resulted in more than a doubling of the agricultural research intensity ratio in 20 years' time. In contrast, the R&D opportunity curve for the developing countries has moved only slightly. This leads to the following postulate:

> *(5) Differences in research intensity across countries and industries and over time are due primarily to differences in the number of profitable innovation opportunities.*

6. *Possible explanations for the underinvestment gap*

While Ruttan's claim that there is substantial underinvestment in agricultural R&D has been generally accepted, it has not been completely undisputed. Pasour and Johnson, for example, argued in their critique of Ruttan's claim that:

> "The only legitimate conclusion that can be drawn when the analyst's estimates do not coincide with those of his subjects' is that the analyst has incorrectly estimated the expected cost and benefits as perceived by decision makers." (Pasour and Jonhson 1982, p. 306)

This argument is of course also valid for the underinvestment gap as estimated by our model. In other words, are there rational explanations why underinvestment gaps exist and why they are so much bigger in developing than in developed countries? Such explanations may provide useful insights into how underinvestment gaps could be reduced.

The model to estimate the underinvestment gap assumes full information and economic rationality. In reality, however, information by which R&D projects are selected is usually incomplete and of a rather uncertain nature, while the selection itself may adhere to economic rationality only partially. Both factors make that governments are unable to pursue the full economic potential of agricultural R&D in an effective way.

Due to lack of information, governments have only an incomplete and vague idea of the economic potential of (agricultural) R&D investment. Even ex post, we have to content ourselves with rather imprecise estimations of the economic impact of past R&D investments. In that sense we are very much groping in the dark, not only ex ante but also ex post.

Some of the explanations of the underinvestment gap in agricultural R&D suggested in the literature are based on the notion that the data used in the rate-of-return calculations is systematically biased. Oehmke (1986), for example, argued that rigidities in the budget process prevent an immediate response to new agricultural R&D investment opportunities. He captured this in a model by basing R&D investment decisions on prices and quantities of period T-1 rather than period T. On the assumption that both variables increase over time, the R&D benefits across all projects will be underestimated ex ante. This results in a persistent underestimation of the position of the R&D opportunity curve causing underinvestment in agricultural R&D.

Another argument put forward by Fox (1985) is that the costs of public agricultural R&D are systematically underestimated. His argument is based on a widely accepted notion in the public-finance literature, namely that the social opportunity cost of a dollar of government spending is larger than a dollar. There are direct costs to collecting taxes, but what is more important is that taxes introduce distortions in factor and product markets that create deadweight economic losses. Ballard, Shoven, and Whalley (1985), for example, estimated the marginal welfare costs or excess burden for the US in the range of $0.17 to $0.56 per US dollar tax income. Fox (1985) assumed an excess burden of $0.30 for every US dollar of tax income, while the US Federal Government advises since 1992 to use $0.25 in rate-of-return calculations of Federal Government projects (Office of Management and

Budget 1992). Whatever rate one agrees upon, such increase in R&D costs affects all R&D projects and hence shifts the R&D opportunity curve down. However, to our knowledge none of the reported rate-of-return studies in our sample have actually included an excess burden rate in its calculations. This means that, collectively, R&D opportunity curves are portrayed too optimistically.

Although often seen as a rather typical US, anti-government sentiment, the influence of the literature on excess burden on taxation policies has been quite significant worldwide. Very few countries, however, actually use an excess-burden rate in their evaluations of government programs. Nevertheless, it does not mean that it is not a factor of importance in making a decision whether or not to fund a government program. Politicians want to be reelected and they know that they do not make themselves popular by raising taxes unless they can show that the programs that are being funded bring significant (economic) benefits to society. The excess-burden rate makes this economically rational resistance to taxation explicit and provides an explanation of why, when no provision is made for the excess burden factor, politicians apparently stop funding agricultural R&D projects (or for that matter any other government project) before the marginal project hits the social cutoff rate.

As already discussed in section 3, the uncertain and risky nature of the economic potential of an R&D investment is another dimension that may very well affect the level of investment in agricultural R&D. Discounting for this risk and uncertainty will shift the position of the ex ante R&D opportunity curve down. Ex post, this expresses itself in an underinvestment gap.

Even when full and accurate information could be assumed, the selection of R&D projects is influenced by many other factors that skew it away from the economic optimum. Stakeholder participation and political lobbying, for example, contribute positively by bringing more accurate and relevant information to the selection process of R&D projects and the setting of an R&D agenda. Its downside, however, is that the outcome of this process may not necessarily be balanced. De Janvry *et al.* (1989), for example, argue that in a typical dual-economy setting rich farmers, because of their better political lobby capabilities, skew the selection of R&D projects into their favor. In such instances, transparent priority setting procedures that manage to balance the various political and economic interests are needed to enhance the economic rationality in the selection of R&D projects and hence reduce the underinvestment gap. Similarly, de Gorter and Zilberman (1990) focus on how consumers and producers may have different incentives to lobby for public agricultural R&D. They show that, depending on the allocation mechanism, differences in the incidence of R&D costs and benefits between consumers and producers will result in different levels of public R&D investment, some of which are considerably below the social optimum.

Each of the possible explanations for underinvestment in agricultural R&D listed above only explains a (small) part of the observed gap (Roseboom forthcoming 2002). Jointly, however, they may come a long way in explaining the gap. Moreover, the investment gap is so much larger for developing than for developed countries because of: (a) less precise information; (b) higher uncertainty; (c) more budget rigidity; (d) (probably) higher tax burden rates; (e) less perfect selection procedures; and (f) lack of political will and organizational capacity in society.

7. *Conclusions*

The model presented in this paper helps a great deal in structuring the underinvestment hypothesis. Rather than focusing on the average rate of return as is generally done in the literature, it shifts focus to the rate of return of the marginal R&D project funded. A great advantage of the model is that it defines underinvestment in agricultural R&D unambiguously. To estimate the underinvestment gap, only three parameters are needed: (a) the social cutoff rate; (b) the ex ante, implicit cutoff rate; and (c) the slope coefficient of the ranked distribution. The first parameter is set outside the model, but the latter two have to be estimated. Taking less than full information and compromised economic rationality into account, these latter two can, under rather restrictive but plausible assumptions, be derived from a sufficiently large and representative sample of ex post rates of return on agricultural R&D. The most important findings of the model are:

- Not the *mean* but the *mode* of the ex post rate-of-return distribution is the relevant variable for assessing underinvestment in agricultural R&D.
- Under the assumption of full information and economic rationality, developed countries could have invested about 40% more in public agricultural R&D and developing countries about 135% more. In terms of agricultural R&D intensity (i.e., expenditures as a percentage of

agricultural GDP), developed countries could have invested 2.8% rather than 2.0%, and developing countries 1.0% rather than 0.4% in the period 1981-85.

- Low investment in public agricultural R&D in developing countries is caused foremost by a relatively smaller portfolio of profitable R&D projects to invest in. Underinvestment certainly plays a role (the gap is bigger for developing countries), but it explains only a modest part of the difference in agricultural R&D intensity between developed and developing countries.
- While efforts to reduce the underinvestment gap should continue, more emphasis should be placed on designing policies that help to shift the portfolio of R&D projects higher up on the ERR scale, even at the risk of increasing the underinvestment gap.

The model of the selection of R&D projects presented here is purely neoclassical. By assuming full information and economic rationality, it takes the underinvestment argument to its extreme. The usefulness of the model is not that it is a good approximation of reality, but that it provides a benchmark against which reality can be compared. The estimated underinvestment gaps are conditional – they assume full information and economic rationality in the allocation of R&D resources. In reality, the ex ante selection of R&D projects is suboptimal and this obscures our sight of the underinvestment gap ex post. It has to be eliminated in order to see the underinvestment gap more clearly and to be able to estimate its size. Ultimately, however, the model is useful not because it estimates past R&D underinvestment gaps but because it helps to understand better why they exist. It is such understanding that can help us to create and better exploit the R&D investment opportunities of tomorrow.

One set of explanatory factors relates to the position and shape of the distribution of all potential R&D projects on an ERR scale. There are important differences in innovation opportunities across companies, industries, countries, and over time. Besides pure technological opportunities (which may be enhanced by investing in basic R&D), other factors come into play, such as the size and structure of the market, the rate and speed of adoption, risk and uncertainty, and R&D effectiveness and efficiency. Each of these factors could, if improved, increase R&D benefits or reduce R&D costs and hence create a larger optimal R&D portfolio.

The other set of explanatory factors relates to why governments underinvest in public agricultural R&D. Possible explanations are a lack of information, suboptimal selection mechanisms, budget rigidity, the excess burden due to taxation, and last but not least, a lack of political will and organizational capacity in society. Improvements in each of these factors should bring the underinvestment gap down.

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