Returns from research in economies with policy distortions: hybrid sorghum in Sudan

Mohamed M. Ahmed, William A. Masters *, John H. Sanders

Department of Agricultural Economics, Purdue University, West Lafayette, IN 49707-1145, USA

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Abstract

Conventional estimates of the economic return to agricultural research use market prices for the values of products and inputs; on this basis, economic rates of return are typically well above the cost of capital, suggesting that more investment in research would be socially desirable. But these estimates may be incorrect if, as is often the case, market prices are distorted by market failures or government policies and hence do not reflect social values.

This paper presents a simple, partial-equilibrium methodology with which to improve the measurement of social returns to research by taking account of multiple distortions in the market prices of products, inputs and foreign exchange. The method also takes account of variation in domestic and world prices, making a product tradable in some years and nontradable in others. The method is applied to the case of Hageen-Dura 1 (HD-1), Sub-Saharan Africa's first commercially successful hybrid sorghum.

HD-1 was released in the Sudan in 1983. From the start of research in 1979 to 1992, the HD-1 breeding program had an estimated IRR of 97% when all major policies in the sorghum market, the fertilizer market, and the exchange rate are taken into account. The high rate of return to HD-1 research was due to the program's low cost and rapid payoff, pointing to the potential value of small adaptive research programs, taking full advantage of foreign technology and genetic material to produce locally-appropriate crosses in a short period of time. Even in the highly distorted economies of Africa, such programs can yield very high payoffs.

1. Introduction

Agricultural research leading to technological change is an important source of productivity growth in many countries. Empirical studies estimating the benefits from agricultural research have shown high social payoffs, suggesting that more research would be a good investment (for an excellent survey, see Echeverria, 1990). However, most of these studies value products and inputs at their market prices, whereas the social rate of return to research should be evaluated at social opportunity costs, to account for the income transfers caused by distortions in product and input markets.

The impact on returns to research of a single distortion in product markets has been demonstrated by Oehmke (1988) and by Alston et al. (1988); in this paper we generalize their results to capture the multiple distortions which characterize most developing countries. In particular, we consider both commodity-specific policies affect-

* Corresponding author: Fax. 317/494-9176.

ing product and input (fertilizer) prices, and macroeconomic policies affecting the prices of all tradables relative to all domestic factors (the real exchange rate). This multiple-distortion approach is similar to that of Norton et al. (1995), but instead of asking how changes in policy would affect the impact of research, we ask how the presence of a given policy can be taken into account when measuring the impact of research. Thus, we are concerned with developing better methods to take account of existing policies, while Norton (1995) and coworkers are concerned with methods to calculate the effects of introducing or removing various policies. The distinction is particularly important for ex-post analyses of the past costs and benefits of research, in economies with large policy distortions.

Multiple divergences between market prices and social values are common in both developed and developing countries, and do not always act in the same direction. For example, the Sudanese government has often raised product prices while lowering the exchange rate, and taxed outputs while subsidizing inputs. The magnitude and direction of bias is an empirical question, and depends on the extent of intervention and the economy's response to those interventions.

Martin and Alston (1992) have recently presented a general model capable of providing exact measures of research returns under multiple distortions, but their approach is sufficiently complex that its use in developing countries is unlikely to be widespread. In contrast the model presented in this paper is intended to provide only approximate results but be easily communicated and use a minimum of data, following the well-established partial-equilibrium approach of Griliches (1958) and Akino and Hayami (1975).

Our objectives are: (1) to present a simple methodology with which to take account of multiple distortions affecting research returns within a partial-equilibrium framework; (2) to apply that methodology in the Sudan, providing estimates of the returns to research on the new Hageen-Dura 1 (HD-1) sorghum. The central hypotheses are that (a) taking account of distortions will significantly affect the social returns to sorghum research, (b) taking account of only one distortion

will give a misleading picture, since some distortions work in opposite directions, and (c) the net returns will remain high when all major distortions are taken into account. These hypotheses are tested empirically, and the magnitude of research returns is estimated.

Measuring the returns to HD-1 research is important in part because HD-1 represents an important test case: it is the first commercially successful hybrid sorghum in sub-Saharan Africa, where the combination of policy distortions and technological difficulties has led to a much slower diffusion of improved varieties than in other regions. The technical achievement behind HD-1 has been well documented by Ejeta (1988); this paper addresses the economic impact of hybrid sorghum research.

2. Hybrid sorghum in the Gezira Scheme

Hybrid sorghum in the Sudan has been adopted primarily in irrigated areas, notably the vast Gezira Scheme. The Gezira's initial purpose was to produce cotton for export, but sorghum has been included in farmers' rotations since the irrigation dam was completed in 1925. Today the scheme consists of 102 000 farms ranging from 6 to 17 ha, producing cotton, wheat, groundnut, and vegetables as well as sorghum. For details of the scheme's operations and performance, see D'Silva (1986), Holdcroft (1989), Nichola (1994) and Sanders and Ahmed (1995).

Research on hybrid sorghum was begun in 1979 by the ICRISAT–Sudan Cooperative Program for Sorghum and Millet Improvement, hosted by the Agricultural Research Corporation (ARC) of Sudan[1]. Hageen Dura 1 (HD-1), Arabic for hybrid sorghum 1, was released in 1983; rela-

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[1] The ICRISAT–Sudan program agreement was initiated in 1977, but research did not begin until 1979. In calculating rates of return we use the later start date, to reflect the year in which funds were first expended, i.e. the year in which interest obligations on borrowed funds would begin.

tively rapid release, after only five years of work, was made possible by close cooperation between the Sudan program and sorghum researchers overseas, including the sharing of inbred lines. After the 1984–1985 drought, high sorghum prices drew public agencies and 11 private companies into HD-1 seed production, and there were substantially increased seed sales for the 1985–1986 crop year. When normal rains returned, production rose and prices fell, slowing further adoption of the new hybrid. Prices rose in 1988–1989, and diffusion of HD-1 has again accelerated. In spite of a considerable expansion in public seed production of HD-1 during 1990–1991, the inability of seed and fertilizer producers to respond rapidly to high sorghum prices remains a principal short-run constraint on HD-1 diffusion.

Table 1 documents the performance of HD-1 relative to traditional varieties. The hybrid responds well to crop inputs, and attracts much higher fertilization levels than traditional varieties; at low input levels, HD-1 and traditional varieties have similar yields.

Table 1
Average sorghum yields for HD-1 and traditional cultivars on farmers' fields in the Gezira with alternative levels of fertilizer use

Cultivar	Fertilizer level (kg ha^{-1})		Average yield (mt ha^{-1})
	Urea	Superphosphate	
HD-1	190.0	95.0	3.28
HD-1 [a]	95.0	95.0	3.07
HD-1	190.0	0.0	2.84
HD-1	95.0	0.0	2.35
HD-1	47.5 [b]	0.0	2.05
HD-1	0.0	0.0	1.17
Traditional [a]	47.5 [b]	0.0	1.45
Traditional	0.0	0.0	1.13

[a] Farmers' standard practice.
[b] Above zero and less than 95 kg^{-1} ha^{-1}. Mean values are utilized.
Source: Authors' field surveys.
Notes: These data were from interviews in 1990 of 56 farmers in four different regions of the Gezira Scheme. Yields are the average for the seasons of 1984–1989. Data were recorded only when farmers expressed certainty about the specific values.

3. Extent of market distortions

In Sudan, as in many other countries, there is substantial government intervention in the prices of specific agricultural products and inputs, and also in the exchange rate affecting the prices of all traded goods. In this paper both types of intervention are taken into account.

The effects of commodity-specific policies are measured by comparing domestic prices for sorghum and fertilizers with estimated trade parity prices: the product's border value in exports or imports, plus or minus inland transport and marketing costs. This takes account of product taxes and subsidies, including the effects of any quantitative controls and the government's own purchases or sales, assuming that quantities traded do not affect foreign prices.

In recent years, the domestic price of sorghum has been kept well above its value in trade: the estimates used in this paper show average domestic sorghum producer prices to have been 69% above average trade parity prices at the official exchange rate in the 1980s. In another study, this difference (the Nominal Protection Coefficient) for foodgrains as a whole was estimated at 63% during the same period (Elbadawi, 1989, p. 49). Subsidization of sorghum producers at the expense of consumers makes the returns to sorghum research appear higher than they are: returns would be lower when sorghum is valued at its social opportunity cost than when it is valued at its market price. In Africa, such production subsidies are rare for export crops, which have been typically taxed at the sectoral level (for example, Schiff and Valdes, 1991, pp. 18–19). Even in the Sudan, most cash crops are taxed; during the 1980s for example, the producer price of Gum Arabic was only 40% of its international market value at the official exchange rate (World Bank, 1987).

The effects of macroeconomic policies are taken into account by valuing trade parity prices at the estimated equilibrium exchange rate, rather than the official exchange rate. This captures changes in the overall price level in the Sudan relative to her trading partners. When fiscal and monetary policy raise inflationary pressure in the

Sudan, the net demand for foreign exchange rises and the equilibrium exchange rate must fall in order to maintain a given current account balance. During the 1980s Sudan had a multiple exchange rate system, and devalued these rates several times (World Bank, 1987, p. 18). But devaluation was insufficient to offset domestic inflationary pressure; as a result, the Sudanese pound (LS), at the official exchange rate, remained substantially overvalued throughout the 1980s, by an estimated average rate of 79%[2].

Exchange-rate overvaluation imposes an implicit tax on sorghum exports, acting in the opposite direction from commodity-specific policies. Using average prices for the 1984–1992 period after release of HD-1 sorghum, opportunity costs taking account of both commodity-specific and macroeconomic distortions are 23% below market prices for sorghum, and 31% above market prices for fertilizer[3]. These period averages sug-
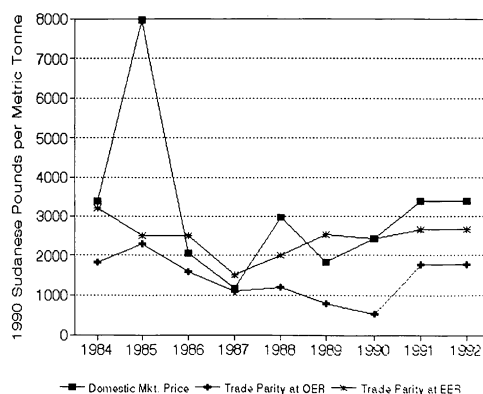

Fig. 1. Sorghum prices and opportunity costs in the Sudan, 1984–1992.

gest that the social profitability of adopting a new more fertilizer-intensive crop variety like HD-1 is much lower when policies are taken into account than when they are not. But these averages conceal a great deal of year-to-year variation in both market prices and trade-parity opportunity costs. Actual values for each year are shown in Fig. 1 for sorghum prices, and Fig. 2 for fertilizer. Clearly, market distortions of this magnitude and complexity must be carefully netted out on a year-by-year basis for the calculated returns to research to reflect its true social benefits.

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[2] The degree of overvaluation was calculated using real exchange rate indexes (Helmers, 1988), with the target level of the index being that which held in 1972 when the nominal exchange rate was LS 0.58 per US$ and the current account was nearly in balance (Youngblood et al., 1982, p. 23). Thus the degree of overvaluation in each year is calculated as the proportional change needed to maintain a constant multilateral real exchange (MRER) index, defined as

$$\text{MRER} = \left(\sum_i w_i E_i P_i^* \right) / P$$

where w_i is the trade share of the ith trade partner, used to weight its wholesale price level (P_i^*) and nominal exchange rate (E_i), and P is the domestic consumer price index, all taken from the International Financial Statistics of the International Monetary Fund (various years). This approach is only approximate; for more exact results a complete model of equilibrium exchange rate formation would be needed. For a discussion of some key limitations of the RER approach in the African context (see Masters, 1991).

[3] For the period 1980–1986, trade parity values for sorghum and fertilizer were considered the actual export realization and actual import costs, respectively. Such data were not available for 1987–1990, so for those years trade parity values were extrapolated from world market prices by adding the average premium paid or received in the earlier years for sorghum (56%), and fertilizer (43%). Sudanese sorghum receives a premium because of its white color (Food and Agriculture Organization, 1988, p. 12).
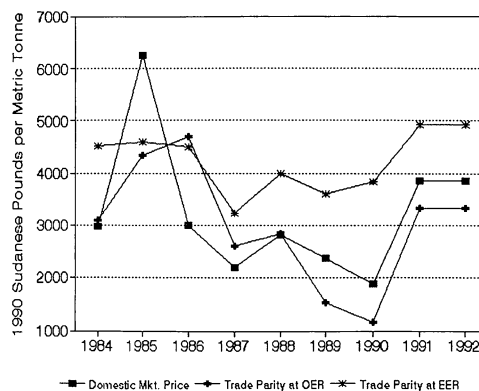

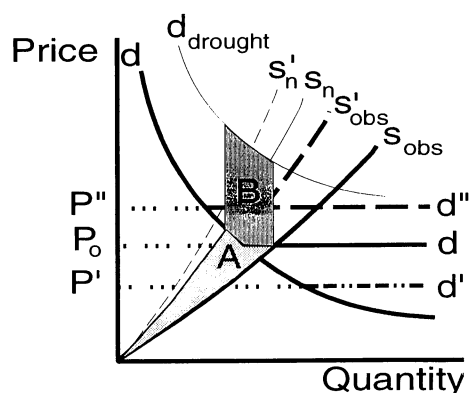Fig. 2. Fertilizer prices and opportunity cost in the Sudan, 1984–1992.

Fig. 3. NSG without taking policies into account.

4. Modeling the returns to research

Following Griliches (1958) and Akino and Hayami (1975), perhaps the most frequently used method for analyzing the welfare effects of technological change in agriculture has been to calculate economic surplus in a partial-equilibrium framework. In this approach, social returns to research are measured as the changes in consumer and producer surpluses resulting from a shift in the market supply curve. Following Akino and Hayami (1975), we assume a pivotal divergent shift; this gives a relatively conservative measure of welfare change (Lindner and Jarrett, 1978, p. 49).

Fig. 3 presents a standard partial-equilibrium model of the impact of research in a small exporting country. In any given year the observed supply curve (S_{obs}) is below that which would have occurred with no research investment (S_n). In our model the supply curve represents only production within the Gezira Scheme, while the demand curve (dd) represents net national demand facing farmers on the scheme: total national consumption minus production elsewhere in Sudan, plus exports. Because export demand is much more price-elastic than domestic demand, the aggregate demand schedule is kinked at the export parity price (P_o); in this model the export price is fixed, abstracting from any large-country effects. Given the kinked demand curve (dd), the net effect of lowering supply costs from S_n to S_{obs} is

a net social gain (NSG) of area A, which can be calculated using a modified Akino–Hayami formula

$$NSG_1 = P_e Q_e \frac{\left(k + 1/2k[k(1+\gamma)]^2\right)}{(\gamma + \eta)} + 1/2X(P_o - P_e) \qquad (1)$$

where k is the rate of shift of the supply curve due to the new technology, X is quantity exported and γ and η are the demand and supply elasticities.

In the case of a drought, supply in the Gezira is unaffected but production elsewhere falls, so demand for Gezira sorghum rises to $d_{drought}$-suspending exports and yielding an additional net social gain of area B, for a total NSG of

$$NSG_2 = NSG_1 + \left(d_{drought} - d\right)(Q_o - Q_n) - 1/2X(P_o - P') \qquad (2)$$

During the period of study there were 3 drought years (1985, 1990 and 1991) in which sorghum effectively became nontradable.

In fact, the observed market supply and demand curves do not reflect all the costs and benefits associated with sorghum production. In addition to market forces, there are externalities and transfers caused by missing markets and government policies. These divergences can be added to or subtracted from market prices to reveal the underlying social supply and demand curves. On the demand side, export subsidies paid by taxpayers raise the observed domestic price for sorghum (P_o) above its opportunity cost in trade (P'). Thus, the social demand curve, taking account of export subsidies, is dd'. At the same time, macroeconomic policy has lowered the prices of all tradable goods relative to all nontradables, by the degree of exchange rate overvaluation. The actual opportunity cost value of sorghum is its trade parity at the equilibrium exchange rate (P''), at which the social demand curve is dd''. The net effect of both commodity-specific and macroeconomic policy together is to lower the domestic price of sorghum from its opportunity cost (P'') to its market price (P_o). In so doing, the government transfers income from sorghum pro-

ducers to sorghum consumers and all those with access to imports at the overvalued exchange rate.

Sorghum is not the only commodity affected by distortions. At a minimum we must also consider how commodity-specific and macroeconomic policies affect fertilizer prices, and hence the costs of production. This is particularly important since the new variety is relatively fertilizer-intensive, so fertilizer is a much larger proportion of costs under the observed supply curve than under the no-research supply curve. Other costs such as labor, land and implements, are relatively similar under S_n and S_{obs} and so distortions in their prices will have little or no effect on the gains from research. To limit the clutter, Fig. 3 shows only one pair of social supply curves, S'_n and S'_{obs}. These reflect the combined effect of the exchange rate and fertilizer-specific policies on the price of fertilizer and hence the costs of production. Because the net effect of the two policies is to lower the cost of fertilizer, the social supply curves (S'_n and S'_{obs}) are both above the market supply curves (S_n and S_{obs}). But since fertilizer use is larger with HD-1 than with traditional varieties, the divergence between S_{obs} and S'_{obs} is larger than between S_n and S'_n.

To take account of policy we need to increase or decrease areas A and B by the amount of the divergence between market and social prices. In so doing, we assume that the policies remain in place. We are not modeling what would happen if the policies were removed; we seek only to measure the gains from research more accurately, capturing information on social opportunity costs which is omitted in traditional models. To show the importance of complete accounting, we will capture this information in two stages: first we take account only of the distortion in sorghum prices from export subsidies, then we will also take account of fertilizer subsidies and exchange-rate overvaluation. Returns calculated with the final method represent our best estimate of the true social gains of HD-1 research.

The first divergence to take into account is that caused by the export subsidy in normal years. Taking account of this cost reveals that although exports were valued at P_o in the calculation of

area A, only P' was actually received, and the actual NSG is

$$\mathrm{NSG}'_1 = \mathrm{NSG}_1 + X(P_o - P') \tag{1'}$$

In drought years there is no export subsidy, so the NSG is unchanged

$$\mathrm{NSG}'_2 = \mathrm{NSG}_2 \tag{2'}$$

Taking account only of export subsidies can be misleading however, since it omits the effects of other important policies and market failures. In particular, we wish to consider the effects of exchange rate overvaluation and fertilizer subsidies. Overvaluation implies that the revenue from sorghum exports is worth the price paid to exporters at the official exchange rate (P'), plus the value of the foreign-exchange premium; the total value is P''. We would also like to take account of the combined effect of subsidies and overvaluation on fertilizer prices: as noted above these divergences imply that the opportunity-cost supply schedules (S'_n and S'_{obs}) are both above the market supply curves (S_n and S_{obs}). Taking account of all divergences thus yields a normal-year NSG of

$$\mathrm{NSG}''_1 = \mathrm{NSG}_1 + X(P'' - P_o) - s_{obs}Q_o + s_nQ_n \tag{1''}$$

In drought years, exports are suspended so the corresponding NSG is

$$\mathrm{NSG}''_2 = \mathrm{NSG}_2 - s_{obs}Q_o + s_nQ_n \tag{2''}$$

5. Data

The analytical model presented above gives rise to six distinct ways of calculating the net social gain from research: using only market prices (NSG_1 for normal years and NSG_2 in drought years), correcting for sorghum subsidies only (NSG'_1 and NSG'_2, respectively), and taking account of all distortions (NSG''_1 and NSG''_2). The data needed for each formula were drawn from the authors' field surveys and secondary sources within the Sudan, using the formulae described above. To find the returns to HD-1 research, the net social gains from adoption must then be com-

pared with the cost of creating and disseminating the new technology. To estimate research and extension costs, we need the annual expenditures of the HD-1 breeding program, the cost of extension attributable to HD-1 diffusion, and the value of the hybrid seed (which, unlike fertilizer, is omitted from the marginal costs under the supply curve).

A price elasticity of supply of 0.29 was estimated by the authors, using a constant elasticity response function and 18 years of sorghum area and prices in the Gezira. A price elasticity of demand of −0.8 was adapted from Abdelrahman (1990). The sensitivity of our results to other elasticity estimates is noted below; as was suggested by Akino and Hayami (1975), the aggregate social benefit from research turns out to be not very sensitive to these parameters. Elasticities have a major impact on the distribution of gains between consumers and producers, but that is not a focus of this study.

To estimate the rate of shift in the production function we need the yield increase from HD-1 and its associated fertilizer cost, plus the extent of diffusion. Yield and fertilizer data are given in Table 1. During this period HD-1 yields were over twice the average for traditional varieties, partly because of more efficient use of a given level of moisture and nutrients, and partly because HD-1's greater fertilizer response led to increased fertilizer use.

The extent of diffusion is calculated by estimating the area planted to HD-1 from seed sales data, divided by the total sorghum area in the Gezira which is available from scheme records along with total sorghum production. To ensure a conservative estimate of research returns we do not include any gains after our adoption data end in 1992, although HD-1 continues to be used and to provide significant benefits.

The market prices paid and received by farmers for sorghum and fertilizer were taken from Gezira Scheme records. Sorghum export and fertilizer import price parities at the official exchange rate were obtained as the unit value of sorghum export and fertilizer imports, minus and plus inland transport costs respectively. These data were also used to derive the trade parities at

the real exchange rate by adjusting for the estimated overvaluation of exchange rate.

Data on expenditures for HD-1 breeding research were estimated by the ARC. A single scientist was involved, plus the cost of all support, i.e. technicians, administrative staff, field workers, and one research assistant, in addition to land rent, water charges, and miscellaneous material. The extension costs included the cost of a pilot project for HD-1 promotion conducted between 1984 and 1988, plus subsequent extension costs funded by the Gezira Scheme itself. The latter is assumed to increase in proportion to the level of adoption. Adoption of HD-1 also results in increased costs for seeds which are evaluated at their market price, and increased costs for fertilizer as discussed above.

On the demand side, sorghum is usually exported; the Sudan's share of the global coarse grain market is relatively small, so we have taken the elasticity of demand for its exports to be infinite. But when drought strikes Sudan's rainfed areas, the domestic demand for irrigated sorghum rises and sorghum exports become unprofitable. Import costs have remained above domestic prices in these years, so the product is temporarily nontradable, and the domestic price rather than trade parity is the correct opportunity cost.

6. Results and discussion

The model and data described above permit us to calculate the rate of return to HD-1 research in three alternative ways: (a) using only market prices, thus measuring gains within the sorghum market only; (b) taking account of the distortion in sorghum prices from export subsidies, following Oehmke (1988) and Alston et al. (1988); (c) taking account of all known distortions, thus measuring gains to the economy as a whole. Returns calculated with the third method represent our best estimate of the true social benefits from the investment in HD-1 research, with all costs and benefits evaluated at their social opportunity costs.

Each year's diffusion of HD-1 and its estimated net social gains (NSG) are presented in

Fig. 4. For simplicity, only the net benefits as calculated under approaches (a) and (c) are shown. This graph shows clearly how the annual costs of research were dwarfed by the benefits in the first few years after release—and how the decline in adoption and benefits during 1988 had little effect on adoption trends and total benefits. Fig. 4 also shows that there are generally quite large differences between the gains measured within the sorghum market (method (a)) and at the economy-wide level (method (c)). Traditional methods account for only half of economy-wide gains in 1986, 1987 and 1989. They substantially overstate total gains in 1984, 1988, and 1992. In other years, particularly the drought years with no exports, there is little difference between the two methods.

To summarize the benefits from HD-1 in a single number, we calculate the internal rate of return (IRR) and net present value (NPV) of this stream of net gains, over the period from 1979 (the start of research) to 1992 (the end of available data). The discount rate used in the NPV calculation is 10%, which is roughly the opportunity cost of government funds. These figures are presented in Table 2, for each of the three measurement methods.

Using market prices without any correction for policy effects yields a historical IRR of 96%, and an NPV in 1979 of 157 million Sudanese pounds (at 1990 prices) or US$35 million (at the official
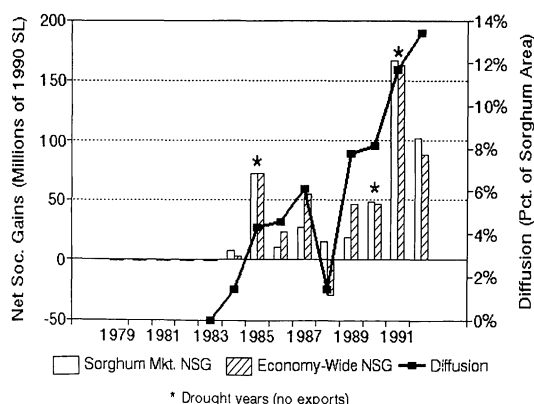
Table 2
Estimates of the internal rate of return and net present value of public investment in HD-1 research for the Gezira Scheme

Measure	Modeling approach		
	(a) With no distortions taken into account	(b) With only the export subsidy taken into account	(c) With all distortions taken into account
Internal rate of return (%)	96	53	97
Net present value [a] (millions of 1990 SL)	157	72	160

[a] NPV calculation is made with a social discount rate of 10%.
Source: authors' calculations.

1990 exchange rate). Taking account of the sorghum export subsidies alone reduces the estimated net return to 53% and an NPV of LS 72 million. But this lower level is misleading, because there are macroeconomic policies which more than offset the sorghum export subsidies: modeling approach (c), taking all policies into account, shows the actual social IRR to have been 97% and the actual NPV to have been LS 160 million, or US$36 million at the official 1990 exchange rate. Accounting for all distortions using economic opportunity costs reveals the returns to research to have been slightly higher than they are at market prices. In all cases, the very high rate of return strongly supports the general conclusion that there has been under-investment in agricultural research in the Sudan. These results are insensitive to variations in price elasticities of supply and demand: the base case elasticities produce an intermediate estimate of research returns, with other plausible combinations yielding slightly higher and slightly lower IRR and NPV results.

7. Conclusions and implications

A key factor driving the very high return to HD-1 research is the relatively low cost and rapid success of the research. By borrowing techniques and germplasm from other research programs, a

Fig. 4. Net social gains and diffusion of HD-1 in the Gezira Scheme of Sudan, 1979–1992.

single scientist was able to obtain a large payoff in a short period of time. This achievement underscores the importance of cross-border spillovers in determining the returns to any particular research program, and hence the role of international cooperation in raising the cost-effectiveness of research.

An additional factor raising the returns to HD-1 research was its quick adoption and the associated rapid rise in fertilizer use, which in turn was made possible in part by the relatively uniform irrigated conditions of the Gezira. Over more varied rainfed terrain, the need for more localized learning about appropriate agronomic practices to control fertility and moisture might have slowed the rate of adoption and of productivity growth, thus reducing the returns to research. The combination of rapid technology release and quick adoption helps explain why HD-1 returns are in the upper range of those reported in similar studies elsewhere, and highlights the value of small, low-cost research programs aimed at adapting existing genetic material to a specific agro-ecological area.

A particular focus of this study has been the development of methods with which to take account of distortions within the partial-equilibrium tradition, without appealing to a formal general equilibrium model. This is made possible in part by taking the existing policy set as given, which avoids the need to estimate how any possible changes in policy would affect research returns. Policy changes are ignored in this model, because policy reforms are not typically within the sphere of influence of those who allocate research funds. As a result, when considering whether research programs are a socially profitable investment, it is appropriate to take policies as given, which gives rise to the methodology proposed in this paper.

In addition to policy effects, we find that a significant determinant of the estimated value of research returns is the larger gains realized in drought years (when the crop is nontradable) than in normal years (when it is exported). Such occasional gains are a major motivation for agricultural research in many countries, so estimates of research benefits which use only average or normal year results and assume that the product

is always traded are likely to be significantly underestimated. This is especially important in drought-prone countries such as the Sudan, where production variability is very large.

This paper demonstrates the feasibility of accounting for policies and variability in research gains without dramatically increasing the complexity of the model. We show that such improvements on traditional impact-assessment methods can be significant, but that care must be taken to account for all offsetting policies. Finally, we show that research on hybrid sorghum in the Sudan—like many other investments in agricultural research—has been highly cost-effective, producing returns far in excess of the cost of capital.

Acknowledgments

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