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Linking technical change to research effort: an examination of aggregation and spillovers effects

Greg Traxler[a,*,1], Derek Byerlee[b,2]

[a] Department of Agricultural Economics and Rural Sociology, Auburn University, Auburn, AL 36841-5406, USA
[b] The World Bank, Washington, DC, USA

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Abstract

We used a disaggregate approach to examine investment efficiency of wheat breeding research in India. India's total research effort comprizes 20 research programs spread across 50 experiment stations. A technology spillover matrix was constructed for both potential and actual spillovers. Spillovers and free-riding were dominant characteristics of technical change during the period studied. Although the aggregate rate of return to wheat improvement research in India was estimated to be 55%, eight programs were found to have earned a negative rate of return when spillins were taken into account. Research output is concentrated on a few strong programs. The two strongest programs generated 75% of all the technical change benefits, even though they claimed just 22% of research resources. These two programs include a significant degree of overlap, while on the other hand many farmers were not reached by any of the programs — 56 and 78% of rainfed and durum area, respectively, in 1990 was still sown with pre-1976 varieties.

Keywords: Technical change; Wheat; India; Spillovers

1. Introduction

Economists have now conducted hundreds of studies to estimate the returns to investment in agricultural research (Evenson and Rosegrant, 1993; Alston et al., 1995). Most have been applied at a very aggregate level of either the state or national research system (Alston and Pardey, 1996, p. 199). Results of these studies have generally confirmed the high payoff to agricultural research, and have been instrumental in influencing policy makers to increase funding for research. However, in many cases, expansion of agricultural research systems has occurred across the board, with relatively little use of economic analysis to decide which programs to establish or enlarge. Most research systems have now ceased to expand and the information provided by aggregate rate-of-return studies is of limited usefulness in today's climate of declining funds. Attention has now shifted to finding means of enhancing the impact of existing levels of research appropriations and to strategically downsizing research programs. To date few attempts have been made to disaggregate rates of return in a manner that corresponds to the operational authority of research administrators who will be guiding the reallocation of research resources among programs.

The value of empirical analyses of agricultural research impacts in allocating research resources has

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[*] Corresponding author. Tel.: +1-334-844-4800;
fax: +1-334-844-5639.
E-mail address: gtraxler@acesag.auburn.edu (G. Traxler).
[1] Associate Professor.
[2] Principal Economist.

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been further limited by difficulties in dealing with the effects of technology spillovers — benefits generated by the adoption of an innovation outside the mandate area of the research institution making the discovery. Spillover effects are, in Griliches' (1992, p. 29) words "both prevalent and important" and, therefore, are an important factor to consider in empirical analyses because their omission may cause the source of research benefits to be attributed incorrectly, biasing the rate-of-return estimates. Studies that have considered spillovers have mainly used some prior notion of 'research proximity' or apparent transferability to focus on the potential impacts of spillins (e.g. Davis et al., 1987; Pardey and Wood, 1994). A few studies have presented econometric evidence supporting such priors (Jaffe, 1986; Evenson, 1991; Maredia et al., 1996; Schimmelpfennig and Thirtle, 1997). But few attempts have been made to directly measure realized technology spillovers of agricultural technologies or to link them to research investments.[3] If technology spillovers can be anticipated, research managers may be able to improve the efficiency of research investments by targeting resources to programs that generate spillovers and eliminating programs that are free-riding on research from more productive programs.

This study examines a large national wheat breeding research effort that comprizes 20 research programs and 50 experiment stations. Ex-post technology spillovers are identified using varietal pedigree and diffusion data. The rate-of-return (ROR) to each of the 20 research programs is estimated using this information. To measure the extent of bias in ROR estimates that would be induced by not taking technology origin into account, these estimates are compared to naive estimates which assume there were no technology spillins from adjoining research programs. We find spillovers to be a dominant force in technical change — 70% of all the technical change emanates from spillovers from other research programs in the national system. This represents important information for administrators seeking to redeploy research resources without risk of reducing the overall availability of technology to farmers.

The specific case examined is wheat breeding research in India. The Indian wheat breeding research effort has been highly successful as measured by widespread adoption of modern semidwarf wheat varieties (MVs) during and following the Green Revolution, and by the high estimated overall return on investment in wheat research (Kahlon et al., 1977; Evenson and McKinsey, 1991). Nonetheless, growth in public funding for agricultural research in India has slowed amid increasing concern about research duplication and overstaffing (World Bank, 1990). Focusing on the post-Green Revolution period subsequent to the widespread adoption of MVs, we estimate the resources deployed in research programs, the rate of genetic gain achieved in each target production environment and the ex-post return on investment for each program, with and without acknowledging the origin of spillovers. We find that although the overall research effort has provided a high return on investment, research output is concentrated on a few strong programs, and research benefits accrue to a concentrated geographic area.

2. Background

India is the world's second largest wheat producing country, with a wheat area approximately equal to that of the US. Wheat production stretches across a north–south distance of nearly 2500 km, under a wide range of agroclimatic conditions, cropping systems, abiotic stresses (primarily heat and drought) and biotic stresses (primarily rust diseases).

The Indian wheat breeding effort is a web of 450 cooperating scientists (203 FTEs), 50 experiment stations (both national- and state-level), and 20 breeding programs. Breeding programs are composed of scientists from one or more research institutes working collaboratively under the All India Wheat Coordinated Program (AIWCP) to test and release varieties for a given production environment. The AIWCP is a directorate of the national Indian Council of Agricultural Research (ICAR) (Paroda, 1992; Jain and Byerlee, 1999). The largest program is that of the Indian Agricultural Research Institute (IARI). IARI is unique in being managed as a single, multi-objective breeding program with a national mandate, conducting research at facilities nationwide. Each of the remaining 19 breeding programs conducts research at several research stations under state jurisdiction, but

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[3] Brennan and Fox (1995) and Evenson and Rosegrant (1993) are two exceptions.

Table 1
Production, research indicators and IRR ignoring spillins, by environment

Production environment	Area 1991 (M ha)	Average yield 1991 (t/ha)	Research expenditure 1991 (M 1989 Rs)	Share value product (%)	Share expend (%)	IRR ignore spillins (%)
Northwest						
Irr timely sown bread	4.9	3.3	4.5	27.1	7.6	71
Irr late bread	3.3	2.9	4.0	15.7	6.7	60
Rain bread	0.4	2.1	2.6	1.5	4.3	52
Irr durum	0.4	3.6	3.0	2.4	5.0	74
Northeast						
Irr time bread	2.0	2.3	4.6	9.4	7.7	49
Irr late bread	4.9	2.0	4.8	19.3	8.0	43
Rain time bread	0.2	1.3	2.7	0.6	4.5	<0
Rain late bread	0.5	1.3	0.8	1.4	1.3	<0
Central						
Irr time bread	1.8	2.3	2.9	8.2	4.9	51
Irr late bread	1.0	1.9	3.6	3.6	6.0	51
Rain bread	1.9	0.8	1.7	3.3	2.9	49
Irr durum	0.1	2.3	1.4	0.3	2.3	<0
Rain durum	0.6	0.8	1.4	1.5	2.4	54
Peninsula						
Irr time bread	0.2	1.7	2.4	0.8	4.0	19
Irr late bread	0.2	1.6	2.1	0.7	3.5	<0
Rain bread	0.1	0.6	1.3	0.1	2.2	26
Irr durum	0.1	1.8	0.4	0.3	0.7	<0
Rain durum	0.5	0.8	1.2	1.2	2.0	19
Hills (all)	0.8	1.5	6.8	2.5	11.3	38
IARI	–	–	7.6	–	12.7	–

receives the major share of its operating funds from ICAR. These programs are administratively classified by geographic zone and by production environment within zones. There are five geographic zones: Northwest Plains Zone (NWPZ), Northeast Plains Zone (NEPZ), Central Zone (CZ), Peninsular Zone (PZ), and Northern Hills Zone (NHZ). Each geographic zone has up to five research programs targeting different environments defined on the basis of: (a) wheat species (bread wheat and durum wheat); (b) irrigation status (irrigated and rainfed) and (c) planting time, (timely planted or late planted as determined by cropping pattern and intensity). A total of 20 significant programs are analyzed in this study (Table 1). Other smaller research projects focusing on breeding objectives such as salinity tolerance, but which do not release varieties are not analyzed.

The size of the mandated production environments for each breeding program varies substantially (Table 1). We use the term 'production environment' to refer to the target environment of a 'research program', e.g. NWPZ irrigated timely bread wheat is a research program targeted at wheat grown in that production environment. The NWPZ, consisting of Punjab, Haryana, western Uttar Pradesh, northern Rajasthan and small parts of adjoining states, is the most important production zone, accounting for just over half of all the wheat production. The NEPZ, primarily comprising of eastern Uttar Pradesh and Bihar provides 29% of production. The CZ consisting largely of Madya Pradesh provides a further 15% of production while the remaining two zones provide less than 5% of the national wheat production. Overall, rainfed wheat occupies 17% of area but produces only 10% of the national output. Three production environments (irrigated timely-planted and late-planted bread wheat in NWPZ and irrigated late-planted bread wheat in NEPZ) account for two-thirds of the total Indian wheat production. Adding the next two largest environments (irrigated timely planted wheat in NEPZ and CZ) brings the cumulative total to 80% of the value of production for these five irrigated environments which receive about 40% of the wheat research resources.

The adoption of MVs closely follows the moisture status of the environment. Practically all the irrigated area is now sown with MVs so that the remaining area under tall varieties is in rainfed areas. Adoption of MVs in rainfed areas is most advanced in the higher rainfall NHZ and NWPZ. In other zones adoption of semidwarf MVs in rainfed areas is negligible, although improved tall varieties have been widely adopted in much of these areas. Average varietal age (average number of years since release weighted by area sown) can be used as a summary measure of the rate at which varieties are adopted and disadopted (Brennan and Byerlee, 1991). The rate of turnover varies sharply in the zones. New releases are most frequently available and more quickly adopted in the NWPZ. Varietal turnover is slowest in NEPZ and CZ.

Although the rate of technical change varies substantially across environments, the research impact of individual programs has not been previously investigated. Such information could be particularly useful in identifying areas for improving the efficiency of wheat-research investments through such measures as scaling back programs from a comprehensive breeding effort to a more limited testing program, or merging programs across either geographic zones for similar environments or merging programs for different environments in the same zone.

The economic analysis proceeds in three sections. First, resources deployed to wheat improvement research in each environment are estimated. Next, data and methods for estimating the research benefits for each environment are explained and internal rates of return (IRRs) are calculated for each production environment using the naive assumption that all technical change benefits are being generated by the 'home' mandate research programs. The final section identifies inter-program technology spillovers and presents IRRs when technology spillovers are correctly attributed.

3. Data and economic framework

Returns to investment in wheat breeding research in India are estimated from benefits accruing for the period 1978–1991, selected to represent the post-Green Revolution period subsequent to widespread MV adoption in irrigated areas. To reflect time needed to develop new varieties, a lag of 10 years between the initiation of research investments and the diffusion of the first varieties generating benefit flows is assumed. Wheat breeding expenditures by environment were not available, so expenditures from the period 1968 to 1991 were reconstructed using three data sources: (a) estimated total national agricultural research expenditures from 1968 to 1986 (Pardey et al., 1991); (b) estimated numbers of total agricultural scientists and numbers of total wheat improvement scientists (Directorate of Wheat Research, 1992; Evenson et al., 1999) and (c) the number of varietal trials by environment.

National research expenditures were deflated using the Wholesale Price Index and then extrapolated to 1991 by assuming that real expenditures increased at the same rate between 1986 and 1991 as they did from 1981 to 1986. The share of total research expenditures allocated to wheat improvement research in all the years was assumed to be the same as the share of wheat improvement scientists, include breeders as well as supporting disciplines of pathology, agronomy, entomology, physiology, nematology and grain quality, in total agricultural research scientists in 1992. Wheat improvement expenditures were then allocated to each zone and environment based on the share of total wheat breeding trials conducted in that zone and environment in a given year. Total expenditures on wheat improvement research in India in 1991 were 1989 Rs 59 million or about US$ 3.5 million. This is consistent with the figure of Rs 150 million for all the wheat research in 1992 calculated from data in Mruthyunjaya et al. (1994), if wheat breeding represents 40% of all the wheat research expenditures.

The economic surplus (ES) generated by wheat improvement research was calculated assuming linear demand and supply schedules and a parallel supply shift (Hertford and Schmitz, 1977). The surplus generated by two types of varietal technical change were modeled (Morris et al., 1994). Type I technical change occurs as modern varieties are first adopted, replacing tall varieties, producing a sharp one-time increase in productivity. The yield gain for Type I varietal change was assumed to be 25% in irrigated areas, 20% in wetter rainfed areas, falling to 10% in dry areas (Byerlee and Traxler, 1995). These yield effects are assumed to be constant through time. The annual increase in production due to Type I technical change generated in each agroecological environment is the yield difference times the base traditional variety (TV) yield times the change in area

$$\text{Type I}\,\Delta Q_t = k^{\text{I}} Y_{\text{TV}} \bar{A}(\text{MV}_t - \text{MV}_0),$$

where k^{I} is the assumed percent yield increase due to adoption of MVs, $\bar{A}$ is the average wheat area in 1977–1990, MV_t the percent of wheat area planted with MVs in year t, MV_0 the area planted with MVs in 1977 and Y_{TV} is the average TV yield in 1977.

Type II technical change occurs in areas that had already replaced TVs with first generation MVs and now periodically adopt newer MVs to replace older generation MVs. This varietal turnover produces a steady improvement in average yield and assures the maintenance of yield stability in the face of evolving pest biotypes. We model the effect of Type II technical change using the trend in genetic gains in yield potential of successive varietal releases. This trend was statistically estimated using varietal trial data by employing the Godden (1998) varietal vintage model. The trials include candidate varieties for release, as well as the main commercial varieties, and usually a long term check. In irrigated areas, this trend was estimated to be close to 1% per year, falling to 0 in some rainfed areas.

The annual production increase due to Type II technical change for each region and environment is

$$\text{Type II}\,\Delta Q_t = (k_t^{\text{II}} - 1) Y_{\text{MV}} \bar{A} \text{MV}_0 (s/d);$$
$$\text{for}\, s < d = (K_t^{\text{II}} - 1) Y_{\text{MV}} \bar{A} \text{MV}_0; \quad \text{for}\, s \geq d.$$

The research-induced yield advantage is assumed to grow at a compound rate, i.e., $k_t^{\text{II}} = (1+g)^s$, where g is the environment-specific annual yield contribution (given in the Appendix), s=(t–1977) and d the average varietal age. Y_{MV} is the average MV yield in 1977, and the s/d term is included to allow Type II impacts to diffuse linearly over the first d years of the benefit period beginning in 1977 before rising to a maximum area equal to the area planted to MVs in 1977.

The combined annual economic surplus generated for each environment is:

$$\text{ES}_t = \frac{P_t Q_t K_t (1 + 0.5K)_t}{(|n| + e)},$$

where K_t is the percentage increase in production attributable to technical change (i.e. the combined supply shift of Type I and II technical change), P_t is the real wheat price and n and e are demand and supply elasticities, assumed to be −0.35 and 0.40, respectively. Wheat prices vary by type (bread and durum), quality, and location of wheat produced. Farmers in NWPZ receive the lowest prices since it is a surplus area specializing in MVs of bread wheats, while farmers in more marginal areas receive higher prices because they produce durum wheats or wheats of higher quality, and because of the cost of transport to bring wheat into these wheat-deficit areas. To compute the IRR for each program, a research lag of 10 years between the initiation of research investments and the initiation of benefit flows is assumed. Benefits were phased in linearly beginning in the 11th year. The speed at which benefits accrued due to varietal adoption was based on the observed weighted average varietal age which ranges from 4 years in NWPZ to 23 years in some environments in the CZ and PZ.

4. Rates of return by program, ignoring spillins

The estimated overall IRR for wheat improvement research in India is 55%. This is high but consistent with other recent studies in India and South Asia (Evenson and McKinsey, 1991; Byerlee and Traxler, 1995). When spillovers are ignored, the estimated IRRs for the individual research programs range from negative to 74% (Table 1). Thirteen of the 19 programs generated an IRR of 19% or above. Only the environments which have had no adoption of MVs, and therefore, no technical change, experienced negative rates of return. Varietal turnover through adoption of successive generations of MVs (Type II technical change) was the dominant source of research benefits for the period, accounting for about 90% of all the benefits of wheat breeding research in India. This represents a major shift from the previous period characterized by the advent of the Green Revolution and Type I adoption of MVs.

The naive analytical assumption used here that ignores spillovers has been commonly used in previous applications of economic surplus models. The model assumes, without verification, that the technical change in each environment is directly attributable to research conducted in that environment. However, without examining spillovers it is impossible to tell which programs are generating output that is a close or even perfect substitute for another program's output. The next section measures technology spillins as a means of more accurately gauging the contribution of each research program to farm level technical change.

5. Rates of return incorporating spillovers

A given production environment enjoys the potential to absorb spillins from adjacent and non-adjacent research programs. A weighting function, $K_{\mathrm{a}}=\sum w_i K_i$, can be used to analyze spillover effects (Griliches, 1992). The weighting function implies that the aggregate supply shift, *K*, experienced in environment *a* is a composite of technology contributed by research conducted by programs in all the environments. Both indirect and direct approaches have been employed to identify the spillover fractions, w_i. (Evenson, 1991). In the following two sections we demonstrate each approach. In the next section the indirect approach is used to estimate the spillover potential based on results from uniform national varietal trials. This analysis reveals some information with regard to research proximity and environmental similarity, but does not provide direct evidence of *actual* spillovers which could be used to calculate program IRRs which account for technology spillins. A later section calculates IRRs based on direct measures of realized spillovers using data on varietal origin and diffusion.

5.1. Indirect assessment of spillovers

A set of linear regression equations was used to assess the potential for technology spillovers among zones for one production environment, following the procedure of Maredia et al. (1996). Varieties developed by the timely irrigated bread wheat programs in each of the five geographic zones, as well as varieties developed by the national program at IARI, were evaluated in national trials from 1967 to 1981. Trials were grown anywhere from 4 to 12 sites in each zone.

Separate regressions were estimated for each zone; the dependent variable in each case was yield in 100 kg/ha. Four types of independent variables were included: (1) origin dummy variables representing the zone in which the variety was developed; (2) a continuous variable representing the first year that the variety appeared in the testing program to proxy for the 'vintage' of the technology; (3) dummy variables for the year of the trial to incorporate weather effects and (4) dummy variables for the site of the trial to account for location effects.

The coefficients of the origin variables can be interpreted as the yield disadvantage (or advantage) of varieties originating in other zones. That is, the first six rows of Table 2 are a potential spillover matrix measured in absolute yield differences (Davis et al., 1987).

Only one origin coefficient is significantly positive in any of the equations. IARI varieties perform well in the NWPZ, with a statistically significant yield advantage of more than 200 kg/ha. This is not surprising since IARI's main research station in New Delhi is located in the NWPZ. IARI varieties also have the highest yields in the NEPZ, but are not statistically different from NEPZ-origin varieties. The spillin potential appears to be limited in the CZ and NHZ, with all origin coefficients having negative signs. CZ varieties appear to have potential for substituting for PZ varieties, although the coefficient is not statistically significant.

5.2. Direct measures of technology spillovers

The spillover matrix estimated above is only a measure of spillover potential since it contains no information on adoption. In this section we use varietal release and diffusion data to examine differences in the productivity of the individual programs, and to reveal realized spillovers. Improved varieties are the primary output of breeding research, so releases are a useful indicator of the strength and potential impact of a research program. The ability to produce releases is a necessary pre-condition for producing economic surplus. A program that is unable to develop any new varieties clearly, has far to go, before it will have any impact on economic surplus. On the other hand, it is possible for a program to name and release varieties that farmers choose to ignore. Many varieties are never adopted, and therefore, have no impact on farm productivity. For this reason, diffusion information

Table 2
Regression analysis of technology spillins among irrigated timely environments

	NWPZ	NEPZ	CZ	HZ	PZ
Dependent variable is yield of varieties tested in zones					
NWPZ origin varieties		−0.98	−1.58	−1.80*	0.31
NEPZ origin varieties	−0.79		−1.60	−0.89	−0.05
CZ origin varieties	−2.05*	−1.25		−1.50	3.00
NHZ origin varieties	−2.58*	−1.47	−2.68		−0.10
PZ origin varieties	−7.07*	−5.59*	−2.71	−1.62	
IARI origin varieties	2.16*	1.24	−0.92		−0.02
Varietal age	−0.01	−0.02	−0.02	−0.06	0.02
1967	−0.62	−7.17*	−7.26*		−27.41*
1969	1.59	0.56	−1.72		
1970	2.56	1.02	3.36	1.58	−9.17*
1971	6.23*	6.71*	14.89*		−12.01*
1972	4.10*	6.80*	5.15*		−10.66*
1973	7.66*	−7.76*	9.01*	−3.86	−17.79*
1974	3.42	−4.16*	13.15*		
1975	1.26	5.85*	9.05*	−9.83*	0.12
1976	2.78*	2.08	7.86*	5.59*	−6.38*
1979	1.80*	−4.79*	8.35*	−1.63	−2.61
1980	6.92*	−7.50*	1.85	0.86	−8.48*
LOC2	−6.41*	0.08	−10.77*	15.43*	9.38*
LOC3	−11.89*	2.06	−7.30*	4.24*	−2.75*
LOC4	−19.11*	−0.28	−2.87*	22.59*	8.95*
LOC5	−9.24*	4.27*	−9.32*	2.20	
LOC6	−13.22*	8.92*	−2.21*		
LOC7	−22.94*	6.58*			
LOC8	−4.87*	−1.37			
LOC9	7.01*	−11.03*			
LOC10	−5.75*				
LOC11	−16.31*				
LOC12	−12.26*				
Constant	47.49*	39.11*	40.44*	25.30*	32.47*
R^2	0.52	0.45	0.41	0.77	0.74
N Obs	1368	596	632	185	258

* Coefficient differs from zero at 10% significance level, standard errors computed using White's heteroscedasticity consistent covariance matrix estimator.

must be also be examined to link changes in farm productivity with research effort. These data must be examined keeping in mind that superior varieties can travel long distances from their institute of release to their zones of diffusion (Maredia et al., 1996; Byerlee and Traxler, 1995).

A total of 138 wheat varieties were released in India between 1976 and 1993, including 42 varieties obtained from the International Maize and Wheat Improvement Center (CIMMYT), based in Mexico (Table 3). CIMMYT itself does not release wheat varieties. It makes varieties available to national programs for testing. The national program may then decide to rename and release the variety. Within the Indian programs, the development of new varieties is highly concentrated. Two programs, NWPZ irrigated timely-sown wheat and IARI, account for 40% of all the Indian releases and the same share of successful varieties (defined as varieties which were sown on at least 25,000 ha in at least one growing season). Ten of the 20 programs had either one or no successful releases, and only three programs had an average frequency for releasing successful varieties greater than once every 5 years. In other words, many zones

Table 3
Varieties released and successful varieties by environment, 1976–1993

	Varieties from Indian crosses	Varieties released from CIMMYT crosses	Total successful varieties released[a]
Northwest Zone			
Irr. Time bread	13	2	8
Irr. Late bread	8	3	5
Rainfed bread	7	2	3
Irr. Durum	1	2	2
Total Northwest Zone	29	9	18
Northeast Zone			
Irr time Bread	8	2	2
Irr late Bread	5	3	2
Rain time Bread	3	0	0
Rain late bread	2	0	0
Total Northeast Zone	18	5	4
Central Zone			
Irr time bread	5	2	1
Irr late bread	3	1	1
Rainfed bread	1	0	0
Irr durum	1	2	1
Rain durum	3	0	1
Total Central Zone	13	5	4
Peninsular Zone			
Irr time bread	2	5	2
Irr late bread	1	0	0
Rainfed bread	1	0	1
Irr durum	0	0	0
Rain durum	2	0	2
Total Peninsular Zone	6	5	5
Hill Zone	4	4	2
IARI	26	14	9
Total for India	96	42	42

[a] Release which was planted to at least 25,000 ha during any 1 year Source: Jain (1994).

experienced technical change despite a lack of research output from their corresponding research institutions. Diffusion information was used to trace the sources of these spillins.

Information on area planted to individual varieties is only available for the 1990–1991 season (Table 4). The table shows the percent of wheat area sown with varieties from each zone by environment. For example the first line of the table indicates that 25% of the irrigated timely-sown wheat area in NWPZ was planted with varieties developed in that zone, while 4% of the area in that environment was sown with varieties developed by CZ, 53% to IARI varieties, 3% to CIMMYT varieties, 15% to varieties released prior to 1976 (prior to the period of analysis in this study). Approximately 10% of total area was sown with unidentified varieties. Table totals are percent of identified area.

Spillovers were indeed prevalent. Just 16% of the total wheat area in India, and just 6% of rainfed area is sown with 'home developed' varieties. A higher share of durum area (37%) is sown with home varieties. The data confirm the dominance exhibited by the release data of NWPZ and IARI technologies in all the zones. Varieties from these zones accounted for a combined 46% of the total area sown in India and 86% of the area sown with identified varieties released since 1976. Varieties from the 15 programs in NEPZ, CZ, PZ and NHZ account for a total of just 9% of sown area despite receiving 61% of national research resources. Nine environments have 60% or more of their area planted

Table 4
Realized technology spillins, percent of area sown to cultivars by zone of origination, 1990–1991

Zone where cultivar sown	Zone where cultivar developed							
	NWPZ	NEPZ	CZ	PZ	HZ	IARI	CIMMYT	Pre-1976
Northwest Zone								
Irr time bread	25	–	4	–	–	53	3	15
Irr late bread	10	–	–	–	–	85	–	5
Rainfed bread	20	–	–	–	–	–	33	47
Durum	26	–	–	–	–	–	74	–
Total: Northwest	21	0	3	0	0	59	5	12
Northeast Zone								
Irr time bread	41	–	–	–	–	–	59	–
Irr late bread	–7	–	–	–	7	–	86	
Rainfed time bread	–	–	–	–	–	–	–	100
Rainfed late bread	–	–	–	–	–	–	–	100
Total: Northeast	13	4	0	0	0	4	19	62
Central Zone								
Irr time bread	65	–	20	–	–	3	–	12
Irr late bread	–	–	77	–	–	–	–	23
Rainfed bread	–	–	–	–	–	14	–	86
Irr Durum	–	–	–	–	–	–	–	100
Rainfed durum	16	–	52	–	–	–	–	26
Total: Central	16	0	26	0	0	8	0	50
Peninsular Zone								
Irr time bread	–	–	–	–	–	82	2	16
Irr late bread	–	–	–	–	–	–	–	100
Rainfed bread	–	–	–	40	–	–	–	60
Irr durum	–	–	–	–	–	–	–	100
Rainfed durum	–	–	–	8	–	4	–	88
Total: Peninsular	0	0	0	6	0	34	1	59
Hill Zones — All	–	–	–	–	6	12	18	64
Total: India	16	1	7	0.3	0.2	30	9	37

to pre-1976 varieties, indicating that much of the area in these environments is not being reached by any of the research programs.

6. Rates of return by program, accounting for spillins

The variety diffusion data were used to recalculate IRRs for each program so that technology diffusion was directly linked to research program investments.[4] Benefits in each production environment were apportioned based on spillover shares. The spillover share w_{ij} is the share of technology from program i used in environment j, calculated as: $w_{ij}=A_{ij}/\sum A_j$, where A_{ij} is the area in environment j sown with varieties released by program i, and $\sum A_j$ is the total area sown with post-1976 varieties in environment j. The use of Table 4, based on varietal diffusion in 1990, to construct weights implicitly assumes that spillovers are constant throughout the period. Data on successful varietal release over time provides support for the idea that release and adoption patterns have been relatively stable.

Incorporating spillins into the analysis reveals a picture of program success which is strikingly different from that presented by the analysis which ignores spillins (Table 5). When surplus generation is more

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[4] Since no estimate of costs was available, and because the focus of the study is on the Indian system, an IRR was not calculated for CIMMYT research.

Table 5
Estimated internal rate of return (IRR) accounting for technology spillins by environment for wheat breeding research in India

	IRR with spillins (%)	Changein IRR (%)	Nat. benefits (%)
Northwest			
Irr time bread	61	−9	31
Irr late bread	32	−28	1
Rainfed bread	37	−15	0.3
Irrigated durum	76	+2	0.6
Northeast			
Irr time bread	<0	−49	0.0
Irr late bread	34	−9	0.8
Rainfed timebread	<0	–	0.0
Rainfed late bread	<0	–	0.0
Central			
Irr time bread	43	−8	5.8
Irr late bread	51	0	3.6
Rain bread	<0	−49	0.0
Irr durum	<0	–	0.0
Rainfed durum	49	−5	0.5
Peninsula			
Irr time bread	<0	−19	0.0
Irr late bread	<0	–	0.0
Rainfed bread	26	−0	0.1
Irr durum	<0	–	0.0
Rainfed durum	14	−5	0.0
Hills (all)	17	−21	0.4
IARI	66	–	45.2
CIMMYT	–	–	10.7

closely tied to identifiable research output, eight programs now have negative IRRs. As would be expected given the heavy concentration of research output noted above, two programs, NWPZ irrigated timely bread wheat and IARI, generate more than 75% of all benefits from an expenditure of 22% of the resources. Nearly all programs in the NEPZ and PZ appear to be free-riding on technologies generated elsewhere. Programs in only two zones, NWPZ and CZ, have been financially efficient at generating technologies for their mandate environments.

Spillovers are clearly a dominant force in varietal technical change in India, accounting for approximately 70% of all surplus produced. The national programs of IARI are responsible for 70% of the spillover benefits, and CIMMYT another 11%. The return on research investment would be much higher if money were redirected from unproductive research programs.

7. Conclusions

In this study, we used a disaggregated approach to examine investment efficiency of wheat breeding research in India, the world's second largest wheat producing country. The evidence we assembled on research output and technology spillovers included three related sets of data; variety release data, variety yield trial data and variety diffusion data. The variety release data is an indicator of research output over a 20-year period. The trial data is an indicator of spillover potential. The diffusion data directly measures technology spillovers at one point in time, late in the period.

The most important finding is that spillovers are the driving force of technical change in the wheat sector in India. The spillovers emanating from two programs generated more than 75% of all the benefits despite consuming just 22% of research resources. The majority of programs produced very modest levels of benefits. The 16 least productive programs combined to produce just 3.7% of national benefits while consuming 69% of research resources. Eight programs were found to have earned a negative rate of return when spillins were taken into account. Clearly there is considerable scope for increasing the overall return on research investment by redirecting money from unproductive research programs.

One of the difficult puzzles is that the successful programs exhibit a very heavy degree of overlap — 80% of all the benefits produced by IARI research which occurred in the irrigated NWPZ. So, to a large extent the two strongest programs were serving the same set of clients. On the other hand, many farmers in the marginal rainfed and durum wheat areas were not reached by new technologies from any programs — 56 and 78% of rainfed and durum, respectively area in 1990 was still sown with pre-1976 varieties. The difficulty in serving marginal environments has plagued many crop breeding programs (Byerlee and Morris, 1993).

Although spillovers and free-riding were dominant characteristics of technical change during the period studied, it is important to continue to monitor technology generation by program in order to establish the degree of stability of spillin patterns over time. How common is it for a program to switch from 'technology borrower' to 'technology generator' status over time? If the pattern is stable, the elimination or redesign of free-riding programs represents a means of increasing the overall rate of return on research investments, at modest risk of reducing technology availability to any of the nation's farmers.

The analysis presented in this paper has two broader implications for conducting studies of rates of return to investment in agricultural research. First, high aggregate rates of return can hide considerable heterogeneity in the performance of research programs that comprise the overall effort. In this case, a high aggregate rate of return to wheat improvement research in India was due to the performance of just two research programs, which absorbed less than one quarter of the resources invested. Second, rates of return are quite sensitive to whether spillovers from other programs are explicitly incorporated. In this study calculations performed under the naive assumption that all technical change was induced by local institutions drew a distorted picture of research productivity patterns. Most studies in the past have ignored such spillovers and have thus biased rates of return to research. Together these results imply that many previous evaluations of investment in agricultural research have underestimated the extent of inefficiencies in investment in agricultural research at the sub-national level.

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