Measuring the Impacts of Improving Research Capacity: The Case of Training in Wheat Disease Resistance

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Abstract
It is notoriously difficult to assess the economic value of research aimed at improving research capacity, particularly in enhancing human capital. In this paper, a framework is developed and an analysis is undertaken of the value of training for scientists in wheat rust resistance in India. The value of the training is assessed through marginal analysis of the improvement in the level of disease resistance flowing from the increased capacity. On that basis, the value of programs to build human capacity through training or further education can be estimated. While such estimates need to be highly qualified, they provide a basis for quantifying the value of R&D capacity building.

Key words: capacity building / training / economic / rust / wheat

Contributed paper presented to the 48th Annual Conference of the Australian Agricultural and Resource Economics Society, Melbourne, February 2004. The views expressed in this paper are those of the authors and do not represent those of NSW Agriculture.

1. Research Capacity and Research Outcomes

1.1 Introduction

Economic assessment of research and development (R&D) in agriculture generally focuses on valuing the enhanced productivity of some or all elements of the farming system. However, in addition to enhancing productivity, a key component of R&D is maintenance research. Maintenance research can be broadly defined as R&D aimed at maintaining the current levels of productivity, and can be measured as the yield losses that would have occurred in the absence of the research investment (Smale *et al.*, 1998).

The outcomes of R&D, whether productivity enhancing or maintenance, will depend on the capacity to undertake that research. Following DANIDA (2000), the capacity to undertake high-quality and effective research involves four components:

- Tangible capital
- Human capital
- Organisational capital
- Social capital

Tangible capital refers to the physical facilities, infrastructure, and capital that underlie and contribute to maintaining or enhancing research, and includes, for example, laboratories, microscopes and molecular marker testing equipment. Human capital refers to the people and their skills, motivation, knowledge, training and experience. Organisational capital refers to mandate, management procedures, policy making procedures, funding arrangements, etc. Social capital refers to the political and economic support for the R&D.

1.2 R&D capacity building

Investment aimed at building research capacity can be an important component of R&D investment, as it enhances the productivity of R&D resources. R&D capacity building can alter the mix of R&D resources available. While there is no clear definition of capacity building in the literature, it can take a number of forms, including:

- laboratories, buildings and glasshouse facilities
- improved R&D machinery and equipment
- provision of field testing equipment
- computerised processes
- scientific training
- "hands on" experience for key personnel
- ability for different scientific groups to communicate with each other
- visiting scholars
- workshops
- exchange of genetic materials
- knowledge of underlying basic science

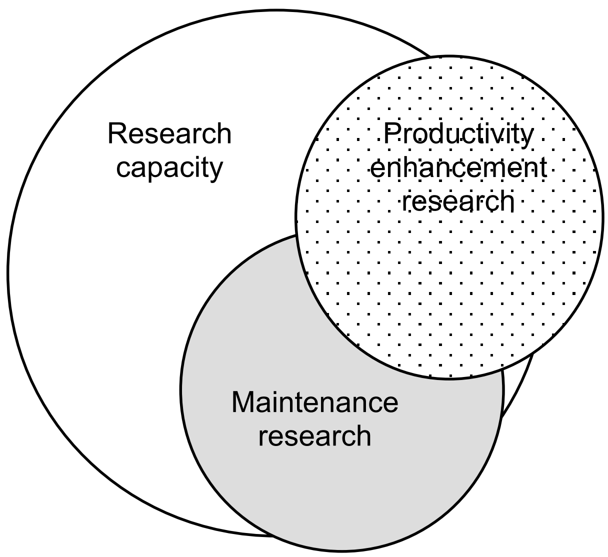
1.3 Linkages between capacity building and research outcomes

As capacity is increased, research outputs can also increase, and the final outcomes can be expected to have higher economic value. There can be minimum threshold levels of R&D capacity below which progress will be very slow, so that there can be a critical mass of capacity before strong progress can be expected (eg, see Maredia and Byerlee 2000, Brennan

1993). There may well also be diminishing returns to increasing investment in R&D capacity in one production environment.

Investment aimed at building research capacity can have an effect through increased productivity, or through increased maintenance research, or through both (Figure 1). Given the presence of research spillovers from one environment to another (Alston 2002), there can be some productivity enhancement and maintenance occur in a particular environment without any R&D capacity in that environment, though generally both require some R&D capacity (Maredia and Byerlee 2000). The larger the capacity, the larger the potential productivity enhancement and maintenance research, and hence the larger the potential economic outcomes.

Figure 1: Research Capacity and Research Outcomes



2. Valuing R&D Capacity and Capacity Building

Investment in capacity building has been an important component of investment in developing country agriculture (eg, Ryan 1999). However, despite the large number of studies that have assessed the extent of R&D capacity building, none have been identified that provided a framework for quantifying the economic value of the increased R&D capacity that has resulted. If informed decisions are to be made about the extent of resources allocated to R&D capacity building relative to direct R&D technologies, some estimates are needed. Therefore, the process of developing a method for measuring the level of returns from investment in R&D capacity building must be one of the most important gaps in R&D impact assessment at this time.

At the basic R&D level, scientists need to develop the capacity to understand, identify and classify the relevant biological aspects of their research before other stages of the process of productivity enhancement can be implemented. When that capacity exists, it needs to be implemented and used to produce improved outcomes before measurable benefits can occur.

Therefore, the research capacity is a necessary but not sufficient condition for the development of improved productivity and/or maintenance outcomes.

Where the capacity is utilised in the R&D program, there will be measurable benefits that flow in future from the improved outcomes (compared to what would have occurred otherwise). The economic analysis needs to identify and measure those improvements in the production environment and in the role of maintenance research.

It is possible that R&D capacity can be improved without any change in the productivity outcomes, as R&D capacity is a necessary but not sufficient condition for the development of improved productivity on farms. However, there may still be benefits in having built the capacity, even if it is not implemented immediately in the R&D program, as such capacity can:

- set the environment for implementation
- enhance benefits once implementation has occurred
- provide training and education for possible future changes (sparks interest in others)
- encourage implementation of improvements in R&D, by identification of gaps in the process

In this paper, the aim is to establish an analytical framework for evaluating the benefits of improving the R&D capacity, and to apply that framework to the training in Australia of wheat pathologists for the management of rust resistance in wheat in India and Pakistan.

3. An Analytical Framework for Valuing Capacity Building

3.1 Analytical framework

Each of the four components of R&D capacity can range from “zero” to “full” capacity. The overall R&D capacity itself is a combination of the components, and the R&D outcomes are a function of the level of each component.

The outcomes are determined by the levels of each of the different components. The relationship between the outcomes and the levels of the components is hypothesised to have the following features:

- The greater the human capital, the greater the productivity outcome, for a given level of the other three components
- The greater the tangible capital, the greater the productivity outcome, for a given level of the other three components
- The greater the organisational capital, the greater the productivity outcome, for a given level of the other three components
- The greater the social capital, the greater the productivity outcome, for a given level of the other three components
- If any of the components is zero, productivity outcomes are determined by the level of technology spill-ins that would occur without domestic research capacity
- If all components are full capacity, productivity outcomes are maximised

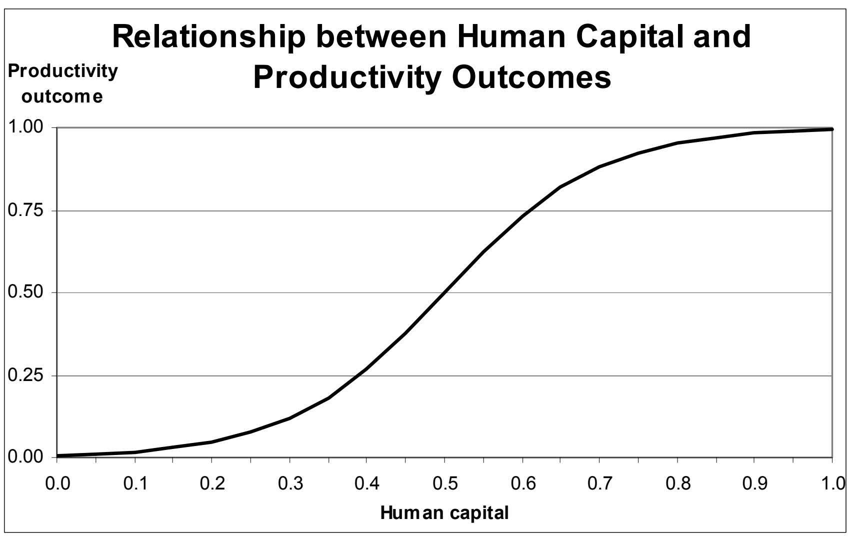
Using these principles, an analytical framework was developed to enable the changes in R&D capacity to be quantified. Within region *i*, the general model for assessing the impact of R&D capacity can be defined as:

$$y_i \quad = \quad f(x_{1i}, x_{2i}, x_{3i}, x_{4i}), \qquad (1)$$

where y_i is the productivity of R&D in region i, x_{1i} is the human capital in region i, x_{2i} is the tangible capital in region i, x_{3i} is the organisational capital in region i, and x_{4i} is the social capital in region i.

The relationship between each of the components and the productivity outcomes is hypothesised as in Figure 2. In the case of human capital (HC), for example, for a given level of the other components of capacity, increases in human capital are likely to follow a logistic curve rather than a linear response. If we assume at this point that there are no technology spill-ins, at low levels of HC in a given region productivity outcomes (PO) are likely to be very small. As HC is further developed, the rate of increase of PO is likely to increase, but then to taper off as HC is increased even further, to the point where diminishing marginal returns set in and additional HC is ultimately unlikely to increase the PO.

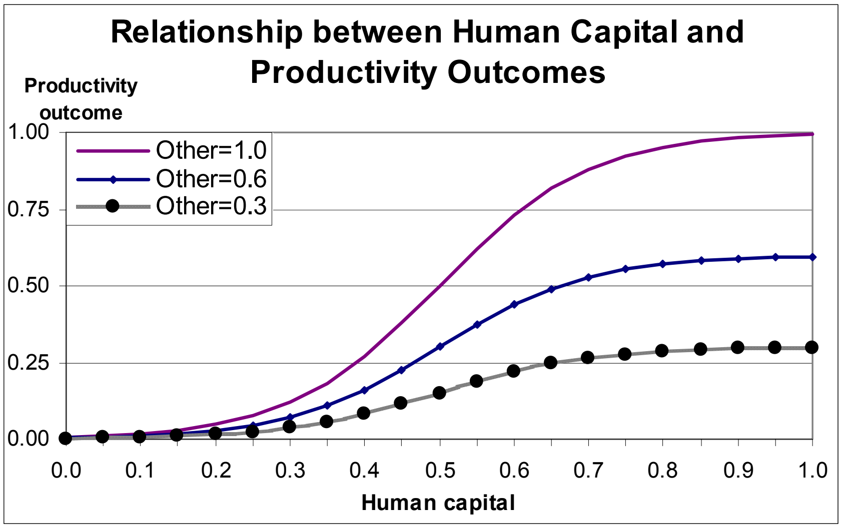
Figure 2: Relationship between Human Capital and Productivity Outcomes



This relationship ignores lags that are likely to occur between a change in research capacity and the resulting increase in productivity outcomes, for simplicity. However, it is feasible to build in a set of distributed lags where the productivity outcome this year depends on the research capacity for a number of past years. The shape and distribution of the weights in any distributed lag system would depend on the nature of the research being analysed.

With different levels of the other components of R&D capacity limiting, different response curves can be identified for increases in human capital. For example, in Figure 3, the PO response to increasing human capital with three different levels of the other components is shown. Where the other components are at 30% capacity, then the response to HC is lower than where they are at 60% or 100% capacity.

Figure 3: Relationship between Human Capital and Productivity Outcomes with Different Levels of Other Capacity Components



It is likely that each of the four components of R&D capacity would behave in this manner with the other components fixed.

3.2 Estimating the relationship between human capital and productivity outcomes
Following Alston *et al.* (1995, p. 357) in their work on adoption curves, the logistic curve can be specified as:

$$y = a/(1 + e^{-(b + cx)}), \tag{2}$$

where y is the productivity outcome in a target region, x is the level of the component of R&D capacity, and a, b and c are parameters to be determined. The parameter a represents the maximum value of y that can be achieved, and b and c are parameters that define the path of the response that asymptotically approaches the maximum.

The question then is how to elicit values that will define the parameters of the logistic curve. Considering the case of human capital improvement (through training, for example), while all other components are fixed, x can represent the years of scientific experience in a region, and y can represent the rate of crop yield improvement per year. The maximum level of yield improvement, a, can be determined from experimental or expert information. If the level of human capital in an area of scientific expertise within a particular region were zero, then productivity outcomes would rely on technology "spill-ins" from other regions or farmer experimentation, so that $y = y_0$ when $x = 0$. In the case where no spill-ins occur[1], then y_0 would be approximately zero. Thus, from equation (2):

$$y_0 = a/(1 + e^{-b}), \tag{3}$$

so that

[1] Spill-ins in this context include both spillovers from other regions and farmer experimentation within the region.. See Appendix A for further discussion and exposition where such technology spill-ins are allowed.

$$a = y_0/(1 + e^{-b}), \qquad (4)$$

This can be re-arranged to give:

$$b = -\log_e(a/y_0 - 1) \qquad (5)$$

Substituting equation (5) into equation (2) and re-arranging, we get:

$$c = (1/x)\ \{\log_e(a/y_0 - 1) - \log_e(a/y - 1)\} \qquad (6)$$

Thus, given a and y_0, we can calculate b. If we define one other point on the curve for which both x and y are known, we can then calculate c, and hence define the entire logistic curve.

Once the curve has been defined, changes in x represent a movement along the response curve. Thus, we can then calculate the expected change in y for a given change in x, and then place an economic value on changes in R&D capacity. A change in one of the other components being held fixed in this analysis would lead to a shift from one curve to another in Figure 3.

3.3 Units of measurement of parameters

For any relationships to be useful in assessing the value of specific R&D capacity building activities, the units of measurement of R&D capacity and the productivity outcomes need to be defined carefully.

If the aim of the analysis is to evaluate the impact of a training program, the units for the human capital component may be expressed in a range of possible measures:

- cumulative years of professional experience
- years of experience post-training
- years of post-graduation work
- the number of workers with a particular qualification
- other measures of research worker intensity

The human capital inputs need to be scaled to the production that is being targeted by the R&D, since for example, 2 qualified workers in a small region may well be adequate to allow productivity to be maximised, whereas that would be inadequate for a very large diverse region with 100 times as much production. Thus the human capital measure needs to be a measure of research intensity (eg, see Scobie *et al.* 1991), and may be expressed in terms such as "years of experience for each hectare of crop sown in the target region".

Similarly, for tangible capital, it needs to be defined in such a way as to capture the productivity of the capital involved. Thus they also need to be scaled to the production that is being targeted by the R&D. Possible measures of research capital intensity include the number of laboratories in a particular region or the money invested in R&D tangible capital facilities, per tonne of crop production in the region.

The other components of R&D capacity, namely organisational capital and social capital, are difficult to quantify for any given region. However, conceptually, it is possible to develop a measure of these components. Again, those measures would need to be scaled to the production in the target region, and would also need to be given equivalence with the scales used in the measures of the other components and the productivity outcomes.

The productivity outcomes need to be related to a measurable outcome such as wheat yields, or the value of disease resistance in each region. The productivity measure needs to be something that will reflect the differences in outcomes form a change in the components of R&D capacity.

4. Defining Rust Resistance Capacity

Due to the genetic flexibility of the fungal rust pathogens, developing and maintaining rust resistance can be difficult. Rust resistance capacity includes the use of resistance genes, but also involves the use of sources of resistance and management of those sources to ensure that the resistance is long-lasting and will minimise the chances of pathogenic changes. Scientists need to have the capacity to understand

- the nature and extent of the variability with pathogen populations
- the genetic basis of resistance in current cultivars
- the genetic basis of resistance in potentially useful germplasm sources

With that understanding, scientists will have the capacity to identify different rust types that they encounter. For example, they will develop an understanding of the roles of specific resistance and non-specific (durable) resistance. Crop resistance to environmental challenges is longer-lasting when more than one specific resistant gene has been incorporated into a cultivar, because it is more difficult for the pathogen to overcome the extra resistance (Watson 1981). However, even multiple gene resistance to a single disease is unlikely to provide a solid foundation for sustained agricultural production (Plucknett and Smith 1986), because the pathogen can mutate to overcome the resistance provided.

Non-specific (partial or horizontal) resistance is the means by which a plant avoids or delays the onset and development of the infection, and thus the resistance is durable. Durable resistance is likely to affect the extent of the losses once the resistance breaks down, rather than the probability of the resistance genes breaking down to the pathogen. In the extreme case, if the mechanisms are such that the disease is unable to develop on a cultivar until very late in the season, the effect of disease infection, even if the cultivar is genetically susceptible to the disease, will be not to reduce yield at all.

Thus, R&D capacity for rust resistance means that pathologists have both the physical facilities and the training and skills to identify different strains of rust, to manage the development of the resistance to those strains, and to work with the breeders to incorporate those resistances into new wheat varieties. These capacities can take a number of forms, including:

- glasshouse facilities and laboratory equipment such as microscopes
- a network of communication with other laboratories and breeders and pathologists
- knowledge of genes for resistance to stem, leaf and stripe rusts
- improved ability to assess rust in the field
- exchange of genetic materials for testing
- development of methodologies for determining rust types, such as populations of fixed breeding lines or genetic markers

- pathogen handling and storage facilities

In Figure 4, the process whereby the development of different levels of capacity in the understanding, identification and usage of rust resistance genes is used to develop improved outcomes for farmers is illustrated. Unless the capacity exists at each of the stages the processes that follow cannot be undertaken. Thus, each level is a pre-requisite for the steps below.

Figure 4: Process of R&D Capacity Building for Rust Resistance in Wheat

1. Understand genes and how they work
- training for pathologists

2. Test material for genes they possess
- need laboratories, etc
- initial level of testing
- widespread evaluation

3. Identify genes in set of varieties
- need laboratories and equipment

4. Devise a strategy to improve and enhance use and deployment of genes
- pathologists need a profile that brings credibility
- need collaboration with breeders

5. Implement strategy (in conjunction with breeders)
- pathologist's profile and credibility
- breeder acceptance of strategy

6. Develop lines and produce an output (ie, variety with resistance)
- breeding
- testing and evaluation of varieties with different pathogens
- effective screening
- molecular markers

7. Outcome of improved resistance in field
- impact on resistance in the field (fewer epidemics, less severe losses)
- impacts on farmers' economic returns

8. Maintenance of resistance over time in face of pathogen mutation capacity
- need genetic materials and sources of resistance to work with (importance of collaboration and international cooperation)
- need capacity and resources to maintain resistance
- need commitment and understanding by funding providers of importance of maintenance

5. Valuing Rust Resistance for Wheat in India

5.1 Productivity outcomes for rust resistance

Following Brennan and Murray (1998), the potential losses from diseases that could have been controlled by resistance can be calculated. In addition, estimates are also available of the current losses that occur in the presence of the current levels of resistance that are employed. These two figures can be combined to determine the extent to which current use of resistance is successful in controlling the diseases. When expressed as percentage of potential losses, the current level of control represents a measure of the success of the R&D capacity in relation to wheat disease resistance. Where other forms of control can be used as well as genetic resistance (see Brennan and Murray 1998), only that proportion relating to resistance is to be included. Thus, the measure of productivity outcomes from disease resistance capacity can be defined as:

$$y_i = \sum_j (r_j (P_{ij} - A_{ij})/P_{ij}), \qquad (7)$$

where y is the productivity outcome in region i, r_j is the relative contribution of disease resistance to the control of disease j, P_{ij} is the potential economic losses in region i from disease j (in dollars) and A_{ij} is the actual current economic losses in region i from disease j (in dollars) given current controls.

5.2 Data

For the purposes of data collection on wheat rust diseases in India, six key production regions were defined. Northern Plains was the dominant wheat production region, although Central and North-eastern regions were also significant producers.

Table 1: Regional Wheat Data for India (Average of five years to 2001-02)

	Area (000 ha)	**Yield (t/ha)**	**Production (000 t)**
Southern Hills	256	0.74	190
Peninsular India	0	1.00	0
Central	6,025	1.76	10,590
North-Eastern India	2,601	2.05	5,323
Northern Plains	15,682	3.01	47,259
Northern Hills	1,558	2.06	3,212
Total India	**26,122**	**2.55**	**66,574**

Data on the productivity outcomes for rust resistance in wheat were obtained from a survey of wheat pathologists in India. Scientists were first asked to estimate the incidence and severity of each of the three main rust diseases (stem, leaf and stripe rust) for each of the six main wheat production regions in India. The results are shown in Table 2. For each of the rusts, there are regions where the potential (uncontrolled) level of severity in the event of a disease outbreak is given a score of 4.0 ("severe") or 4.5 ("severe" / "very severe") out of a possible 5.0. However, given current controls, the present severity of the diseases is 2.5 ("light" / "moderate") or lower. The incidence scores indicate that environmental the conditions for the rusts are such that the rusts are generally "localised" (scores 2-3) although in some regions the scores are 1.0 ("rare") or 4.0 ("widespread in some seasons").

Table 2: Scores for Disease Severity and Incidence for Rust Diseases in India

	Stem Rust			Leaf Rust			Stripe Rust		
	Severity		Incidence	Severity		Incidence	Severity		Incidence
	Potential	Present		Potential	Present		Potential	Present	
Southern Hills	4.5	2.5	4.0	4.0	2.5	3.5	3.5	2.5	3.0
Peninsular India	4.5	1.0	2.5	3.5	1.5	2.0	0.0	0.0	0.5
Central	4.5	1.0	2.5	3.5	1.5	2.0	0.0	0.0	0.5
North-Eastern India	1.5	0.0	0.5	3.5	2.0	2.5	1.0	1.0	0.5
Northern Plains	0.5	0.0	0.0	2.5	1.5	2.0	4.5	1.5	3.0
Northern Hills	1.5	0.0	0.0	4.0	1.5	3.0	4.5	1.0	2.0

Source: Based on a survey of Indian wheat pathologists (Brennan 2004).

Table 3: Estimation of Value of Resistance to Wheat Rusts in India

	Yield Loss (%)		Economic Loss ($/ha)		Loss Total ($'000)		Value controls		% resistance	Value of resistance		
	Potential	Present	Potential	Present	Potential	Present	$/ha	$'000		Potential	Actual	Resistance % Potential
Stem Rust												
Southern Hills	6.40	0.60	7.16	0.67	1,834	172	6.49	1,662	100%	1,834	1,662	91%
Peninsular India	2.13	0.01	3.20	0.02	0	0	3.18	0	100%	0	0	99%
Central	2.13	0.01	5.63	0.04	33,893	212	5.59	33,681	100%	33,893	33,681	99%
N-Eastern India	0.00	0.00	0.00	0.00	2	0	0.00	2	100%	2	2	100%
Northern Plains	0.00	0.00	0.00	0.00	0	0	0.00	0	100%	0	0	100%
Northern Hills	0.00	0.00	0.00	0.00	0	0	0.00	0	100%	0	0	100%
- India Total	***0.36***	***0.00***	***1.37***	***0.01***	***35,728***	***384***	***1.35***	***35,345***	***100%***	***35,728***	***35,345***	***99%***
Leaf Rust												
Southern Hills	3.00	0.38	3.35	0.42	858	107	2.93	750	95%	815	713	88%
Peninsular India	0.60	0.03	0.90	0.04	0	0	0.86	0	95%	0	0	96%
Central	0.60	0.03	1.58	0.07	9,533	397	1.52	9,136	95%	9,057	8,679	96%
N-Eastern India	0.80	0.07	2.46	0.20	6,392	533	2.25	5,860	95%	6,073	5,567	92%
Northern Plains	0.15	0.03	0.68	0.11	10,636	1,784	0.56	8,852	95%	10,104	8,409	83%
Northern Hills	2.00	0.04	6.19	0.14	9,641	214	6.05	9,427	95%	9,159	8,956	98%
- India Total	***0.37***	***0.03***	***1.42***	***0.12***	***37,061***	***3,035***	***1.30***	***34,025***	***95%***	***35,208***	***32,324***	***92%***
Stripe Rust												
Southern Hills	1.00	0.25	1.11	0.28	286	71	0.84	214	95%	271	203	75%
Peninsular India	0.00	0.00	0.00	0.00	0	0	0.00	0	95%	0	0	100%
Central	0.00	0.00	0.00	0.00	0	0	0.00	0	95%	0	0	100%
N-Eastern India	0.00	0.00	0.00	0.00	1	1	0.00	0	95%	1	0	0%
Northern Plains	2.67	0.04	12.06	0.21	189,113	3,359	11.85	185,755	95%	179,658	176,467	98%
Northern Hills	1.60	0.01	4.95	0.03	7,711	51	4.92	7,660	95%	7,325	7,277	99%
- India Total	***1.97***	***0.03***	***7.55***	***0.13***	***197,110***	***3,482***	***7.41***	***193,629***	***95%***	***187,255***	***183,947***	***98%***

Source: Derived from data supplied by Indian wheat pathologists (Brennan 2004).

From these scores, using the methodology explained in Brennan and Murray (1998), estimates were obtained of the total value of resistance to each of the three diseases (Table 3). These values show that the highest level of disease losses per hectare occur in Southern India where wheat production is low, while in the main production regions (Northern Plains, Central and North-Eastern) the diseases are generally more under control. Overall, stem rust causes annual losses of $0.38 million, leaf rust $3.04 million and stripe rust $3.48 million. In aggregate terms, the broad control of stripe rust in the Northern Plains region contributes almost $186 million per year in losses avoided.

Aggregating across the three rusts, for India as a whole, resistance to the three rusts has the potential to provide benefits of $258.2 million per year (Table 4). At present, benefits of $251.6 million are being provided, so that the productivity outcome in terms of rust resistance is 97.5% (=251.6/258.2) of potential. Thus, the productivity outcome for rusts in India is that resistance is providing 97.5% of the potential benefits.

Table 4: Value of Wheat Rust Resistance in India and Productivity Outcomes

	Potential costs ($'000)	Present costs ($'000)	Value of controls ($'000)	% resistance	Resistance potential ($'000)	Resistance actual ($'000)	Resistance % potential
Stem rust	35,728	384	35,345	100.0%	35,728	35,345	98.9%
Leaf rust	37,061	3,035	34,025	95.0%	35,208	32,324	91.8%
Stripe rust	197,110	3,482	193,629	95.0%	187,255	183,947	98.2%
All rusts	***269,899***	***6,901***	***262,999***	***95.7%***	***258,191***	***251,616***	***97.5%***

Source: Derived from Table 3.

6. Valuing Rust Resistance Capacity Building for Wheat in India

Craig *et al.* (1991) and Pardey *et al.* (1991) used the number of full-time equivalents in research, defined by educational status, as their measure of the human capital input into agricultural research. Pardey *et al.* (1991) acknowledged the practical difficulties associated with qualification levels, expatriate researchers and research managers in constructing a measure of human capital in developing countries. Such inherent difficulties remain in this study as well.

In measuring the level of human capital in the area of disease resistance in a region, the most appropriate measure appears to be a combination of the level of educational status and the total cumulative years of post-graduate experience among the plant pathologists in wheat diseases resistance. Given the need to scale the measure, it is expressed as "years of experience per million hectares of wheat sown".

The information on personnel working on wheat pathology was obtained from personal contact with wheat pathologist Dr R.G. Saini, Punjab Agricultural University, Ludhiana, India (personal communication). For India, detailed data were available on the individuals involved in rust resistance work at present. The human capital involves 32 scientists, contributing a total of 20.2 full-time equivalents (FTEs) on wheat rust resistance. The data on the qualifications and experience of those staff are summarised in Table 5.

Table 5: Scientist Numbers in Wheat Rust Resistance in India

Educational status	Scientists (FTE)	Years of experience 0-5 yrs	6-10 yrs	11-20 yrs	21-30 yrs
Master's degree	3.5	2	2	0	0
PhD	16.7	7	7	8	6
- Total	*20.2*	*9*	*9*	*8*	*6*

A number of alternative methods for estimating the total human capital involved as a single parameter were considered. Two methods of measuring the human capital for wheat rust resistance are explored in this paper:

(a) Counting years in study and years of experience in total
(b) Treating MSc experience as less valuable than PhD experience.

In assessing the years in study, the values allocated to different levels of education are shown in Table 6. A basic degree is taken as three years, a Master's degree as two additional years, and a PhD an additional four years. In addition, cumulative years of experience, post-graduation, can be added to this education status score in years. It is arguable whether it is appropriate to include years of experience in a linear fashion, as it is possible that there is diminishing marginal returns to additional experience. However, for simplicity in this study, these are treated in a linear fashion.

Table 6: Estimation of Value of Human Capital

Educational status	Marginal years	Cumulative years
Bachelor's degree	3	3
Master's degree	2	5
PhD	4	9

In assessing PhD equivalents, an (arbitrary) assumption was made that one year of experience with MSc as the highest qualification was equivalent to 70% of one year's experience with PhD qualification.

Allowing for the proportion for the time each individual allocates to rust resistance, the two alternative measures of the current human capital for wheat rust resistance per million hectares of wheat sown in India are:

- Sum of years: 15.4 years/ha
- PhD equivalents: 8.8 years/ha

In addition, two different levels of technology spill-ins are allowed in the analysis:

- No spill-ins

- 50% spill-in, so that resistance is 50% of potential when there is no local human capital

Where we also assume that there are no spill-ins of technologies for rust resistance from other regions, we can take the value of y_0 = 1% when x is zero (remembering that y is asymptotic to the horizontal axis). Where there are spill-ins, y_0 = 50%.

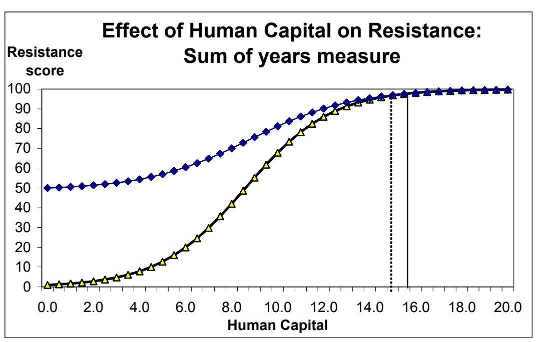
From equation (2), the relationship between human capital for rust resistance and outcomes for wheat rust resistance in India is made. Each specification provides a separate estimate of the relationship. From each relationship, an estimate of the value of a change in human capital can be estimated (ignoring any lags inherent in the system). Using each of these specifications of human capital and spill-ins, the relationship illustrated in Figure 2 is estimated, using equations (5) and (6) to estimate the required parameters. The parameter estimates for equation (2) are shown in Table 7.

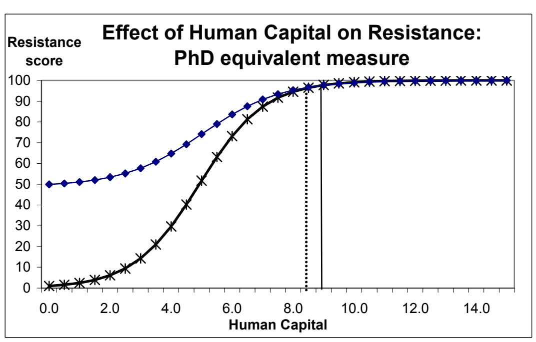
Table 7: Parameters for Alternative Specifications of Human Capacity Curves

Specification of HC	Spill-ins	Productivity outcome (y)	Human capital (x)	Maximum value (a)	Value at axis (y_0)	Param. *b*	Param. *c*
Sum of years	None	97.45%	15.4	100%	1%	-4.595	0.534
Sum of years	50%	97.45%	15.4	100%	50%	-3.912	0.445
PhD equiv.	None	97.45%	8.8	100%	1%	-4.595	0.933
PhD equiv.	50%	97.45%	8.8	100%	50%	-3.912	0.777

The relationships determined from these data are illustrated in Figure 5. The two curves in each case represent those with and without R&D spill-ins.

Figure 5: Effect of Human Capital on Rust Resistance in India





7. Analysis of Further Training in Rust Resistance

7.1 Increase in productivity outcome from training

On this basis, the value of programs to build human capacity through training or further education can be estimated. While there are likely to be many qualifications to any such estimates, they provide a first step in the process of quantifying the value of R&D capacity building.

In determining the effect of bringing three Indian wheat pathologists to Australia for training at the National Cereal Rust Control Program at the University of Sydney, some further assumptions are required:

- Each round of training lifts the human capacity of that individual for a number of years
- The additional value for each year is equivalent to one-half of a FTE of additional experience
- The training has a "life" of 10 years in terms of improving human capacity of that individual

Thus, for each plant pathologist trained, the human capacity in India increases by a total of 5 years. With three Indian scientists trained under the project, the aggregate human capacity at present is 15 years higher than it would have been without that training, under each alternative measure.

Inserting that shift in the equation for each set of parameter estimates, the productivity outcome without that additional human capacity is estimated (Table 8). The annual gain in productivity outcome varies from 0.7% to 1.7%. These gains are valued at between $1.8 million and $4.5 million per year.

Table 8: Value of Training Five Plant Pathologists in Rust Resistance

Specification of Human capital	Spill-ins	Productivity outcome (*y*) With training	Without training	Gain from training	Value of gain ($m)
Sum of years	None	97.45%	96.57%	0.88%	$2.3 m
Sum of years	50%	97.45%	96.76%	0.69%	$1.8 m
PhD equivalent	None	97.45%	95.73%	1.73%	$4.5 m
PhD equivalent	50%	97.45%	96.13%	1.32%	$3.4 m

7.2 Benefit-cost analysis

For an economic analysis of the project, the lags and time-frame need to be estimated. We assume no lags from the end of the project, with benefits beginning in 1991, and remaining at the peak level for 20 years (until 2010). The costs of the project are estimated at $400,000 per year for six years from 1985 to 1990. Using a real discount rate of 4.0%, the results of the benefit-cost analysis are as shown in Table 9. The benefit-cost ratio ranges from 9.2 to 22.9 for the alternative specifications.

Table 9: Benefit-Cost Analysis of Project Training Indian Scientists

Specification of Human capital	PV Benefits ($m)	PV Costs ($m)	NPV ($m)	BCR	IRR (%)
Sum of years	51.6	4.4	47.2	11.7	37%
Sum of years	40.5	4.4	36.1	9.2	33%
PhD equivalent	101.0	4.4	96.5	22.9	52%
PhD equivalent	77.3	4.4	72.9	17.5	46%

Whichever of the specifications of human capital are used, the analysis shows that the project provided a substantial return, with a Net Present Value of at least $36 million, a benefit-cost ratio of at least 9.2 and an internal rate of return of 33% or more.

It is apparent from Table 9 that allowing for spill-ins reduces the gain from the training, by approximately 20% in each case. It is also apparent that the different specification of human capital can lead to significant differences in the results of the benefit-cost analysis. This finding points to the importance of determining the most appropriate measure of human capital. Further work on exploring the best options is needed.

7.3 Limitations and qualifications

The analysis reported in this paper provides a basis for determining the value of a research project aimed at improving R&D capacity. The approach provides a framework for assessing other similar projects in future, and provides a platform for an improved understanding of the economic value of investments aimed at improving research capacity.

However, the analysis involves a number of simplifying assumptions that require further investigation before the framework can be applied more broadly. In particular, areas where further investigation and improved data are likely to lead to improved outcomes from the analysis include further consideration of:

- the nature of the relationship between human capital and productivity outcomes
- the most appropriate measure of human capital
- the role of spillovers and the level of spill-ins likely in each case
- the development of improved measures of the impact of training on the level of R&D capacity
- the lags inherent in the relationships between human capital and productivity outcomes

In addition, more extensive and more disaggregated data are likely to be valuable in enabling further understanding of the role of human capital and consequent productivity improvements.

In conclusion, in this paper a framework is developed for assessing improvements in R&D capacity through training. In applying it to the project on training in Australia for Indian wheat pathologists in rust resistance, a number of elements of the empirical application of that framework are highlighted. While many avenues for improvement and further development remain, the results provide a useful analysis of the impact of the project, and provide a basis for concluding that such training is a worthwhile use of funds for agricultural research and development.

Acknowledgments

We would like to acknowledge the assistance of a number of people who have assisted in the collection of data and information for this work. In particular, we would like to thank Bob McIntosh, Colin Wellings and Robert Park of the National Cereal Rust Control Program at the University of Sydney for their patient assistance is providing details of the projects involved. We would also like to acknowledge the assistance of Dr R.G. Saini, Punjab Agricultural University, Ludhiana, who provided much of the valuable information that has been used in the analysis. John Mullen also provided useful feed-back on an early draft of this paper. We would also like to thank Debbie Templeton of ACIAR and acknowledge the financial support of ACIAR for this work. None of these people bear any responsibility for the errors or omissions in this report.

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Appendix A: Technology Spill-ins

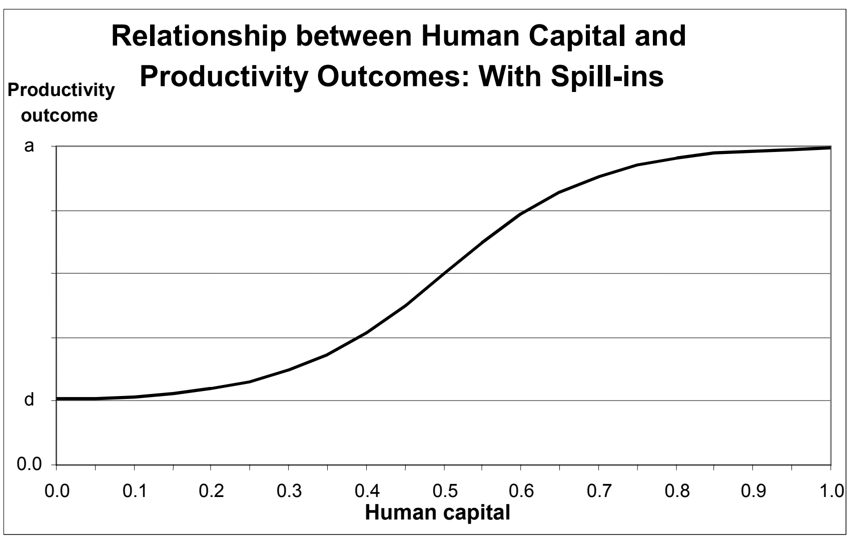
Consider the situation where there are technology spill-ins and/or farmer experimentation (see footnote 1). With no human capital in a region, the productivity outcome would be positive, because of the spill-ins from other regions.

In equation (2), with spill-ins of d where $x = 0$, $y = d$. The maximum level (ceiling) is then $(a–d)$. Thus, equation (2) becomes:

$$y = (a\text{-}d)/(1 + e^{-(b + cx)}) + d, \qquad \text{(A.1)}$$

where d is the level productivity that results from the technology spill-ins from other regions, even when there is no R&D capacity in the target region. The relationship between human capital and productivity outcome is then as illustrated in Figure A.1.

Figure A.1: Relationship between Human Capital and Productivity Outcomes, with Technology Spill-ins from Other Regions



Equations (3) to (6) can be simply extended to incorporate spill-ins if d is known (or can be estimated separately).