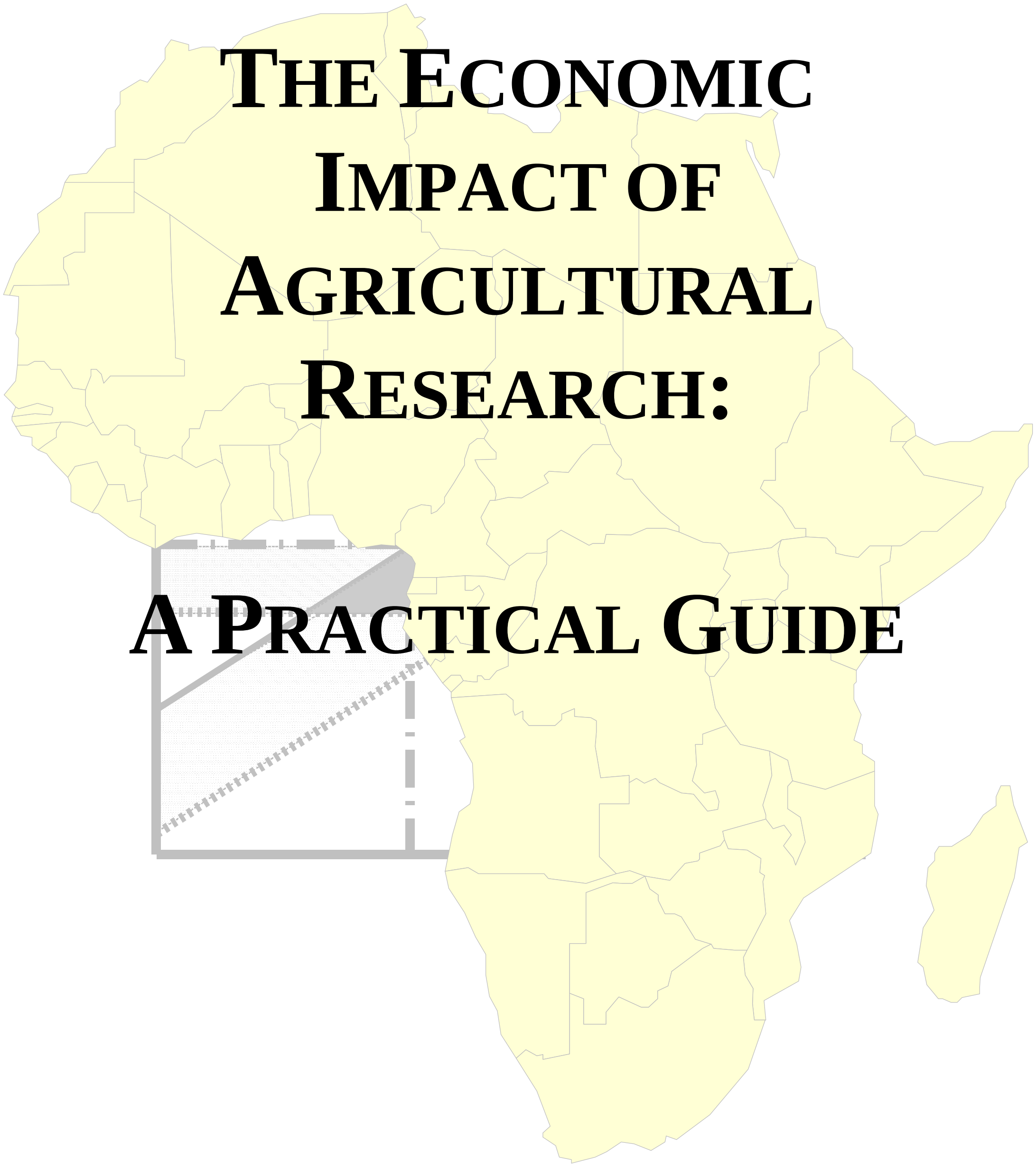


THE ECONOMIC IMPACT OF AGRICULTURAL RESEARCH:

A PRACTICAL GUIDE

THE ECONOMIC IMPACT OF AGRICULTURAL RESEARCH:

A PRACTICAL GUIDE

July 1996

Produced by
William A. Masters

with
Bakary Coulibaly
Diakalia Sanogo
Mamadou Sidibé
Anne Williams

and the assistance of
John H. Sanders
Jess Lowenberg-DeBoer

Department of Agricultural Economics
Purdue University
West Lafayette, IN. 47907
Fax: 317/ 494-9176
Phone: 317/494-4235
E-mail: Masters@AgEcon.Purdue.edu

PREFACE

This manual was written in response to numerous requests from African researchers. Given increasing pressure to document the social benefits of new technologies, more and more scientists are being called upon to measure their impact and present their results to policy-makers. This guidebook is intended to provide a concise summary of the tools needed to conduct persuasive impact studies, enabling any researcher to quantify the economic benefits (and costs) of their work.

The methods presented here have been developed and refined over more than 20 years of experience in measuring the impact of agricultural research. A key lesson of that work has been that successful impact assessment requires the integration of many different perspectives. Agronomists, breeders and other agricultural scientists must be involved, along with economists. This manual is intended to make that possible, by providing practical guidelines in an accessible format.

Three computer exercises help apply the methods described in this manual. The first is a simplified hypothetical example, the second represents the case of sorghum in Cameroon, and the third shows cotton in Senegal--which is also the case-study discussed in boxes throughout the text of the manual. The data needed to perform each exercise are given on the enclosed diskette in files labeled “example1.wk1", “example2.wk1" and “example3.wk1". To run the exercises, researchers should load the relevant file into any spreadsheet software such as Lotus 1-2-3, Quattro or Excel, and then follow the instructions included at the end of this book.

The text and computer exercises are adapted from material developed by the authors for use in several training workshops in Africa; the text also draws heavily from published sources, notably *Science under Scarcity: Principles and Practices for Agricultural Research and Priority Setting* by Julian Alston, George Norton and Philip Pardey (Ithaca, NY: Cornell University Press, 1995). That excellent book should be used by all researchers interested in pursuing further any of the methods suggested in this manual.

The authors wish to thank the Sahel Institute (INSAH) of the Permanent Interstate Committee against Drought in the Sahel (CILSS) for its cooperation, and the U.S. Agency for International Development (USAID) for its support. We also wish to thank the Senegalese Institute for Agricultural Research (ISRA), with whom the study of cotton in Senegal was conducted, as well as the many other agricultural researchers and institutions throughout Africa with whom we have had the pleasure of working.

TABLE OF CONTENTS

LIST OF BOXES

CASE STUDY BOXES

FORMULA BOXES

LIST OF TABLES

TABLES IN THE TEXT

TABLES IN THE CASE STUDY BOXES

LIST OF FIGURES

THE ECONOMIC IMPACT OF AGRICULTURAL RESEARCH: A PRACTICAL GUIDE

INTRODUCTION

Objectives

This manual presents the concepts and tools needed to calculate the economic impact of agricultural research, using real case studies and field data from West Africa. The document is intended to be a practical guide accessible to non-economists. Each concept and formula is developed using a step-by-step approach, with corresponding computer exercises available for hands-on practice.

Who should use this manual?

The document was developed principally for researchers carrying out impact assessments within African agricultural research institutes. In addition, we hope it will be helpful for research managers who may need to interpret the impact assessments carried out by others, as well as other researchers and decision-makers whose work involves the impact of agricultural research at the national and international level.

Why measure the impact of agricultural research?

Resources are scarce. All governments, and all foreign aid donors, need to justify their investments. But the economic value of public investments may not be obvious. It is particularly difficult to observe the impact of agricultural research, because the benefits are diffused over many years and many millions of dispersed producers and consumers. Economic studies are needed to measure those benefits, and compare them with the costs of the research.

With careful evaluation of research impacts, scientists can target their work to achieve the greatest possible payoffs. Documentation of research impacts is also needed to ensure an appropriate level of public support. Without clear and persuasive demonstrations of its benefits, research is unlikely to attract the sustained funding it needs to be successful.

The role of research in the development process

Improvements in technology, driven by the application of scientific research to practical problems, are at the heart of economic growth and development. Improved technologies are necessary to help producers respond to changing circumstances, as well as to raise productivity and real incomes. Technical change in agriculture is particularly important in Africa. Without it, there can be no sustainable economic growth: rapid increases in the population would lead to growing unemployment, malnutrition and resource degradation.

New technologies permit farmers to do more with less. Particular innovations target specific needs, but agricultural research as a whole can help achieve four broad objectives:

- improve overall living standards;
- enhance food security and economic stability;
- reduce poverty by creating jobs and reducing food prices; and
- maintain natural resources, such as water, soils and vegetation.

Agricultural research helps achieve these objectives by providing new knowledge and new materials such as seeds, fertilizers and equipment. Some research is done by private firms, but this is sustainable only when product sales can recover investment costs. As a result, although research into new types of machinery and chemicals is often privately-funded, most research into new open-pollinated varieties, agronomic techniques, and economic policies is not done by private firms. This research generates “public goods”, which once produced are available to everyone. It is therefore typically done in the public sector.

Public goods may not benefit everyone equally. Since different groups have an interest in different types of research, it is common for a national agricultural research system (NARS) to be made up of distinct organizations, each of which uses different guidance and funding mechanisms. A NARS may include some private firms, whose research is aimed mostly at producing marketable products. It may also include universities, whose research is mostly related to teaching activities. Research that is associated with export commodities is often guided (and funded) by commodity associations or marketing firms, since the gains from export-crop research are captured mainly by producers and exporters of that product. But most research on staple foods must be funded and guided by the government itself, since its benefits are spread widely among all consumers.

Because the gains from research are not self-evident, research will not receive appropriate levels of support or guidance unless they are discovered and disseminated through regular impact assessments. Doing so can help:

- document accountability for past funding,
- build a track record to attract new funding,
- build broad awareness to ensure political support, and
- guide the research agenda to achieve national priorities.

BOX 1. THE EXAMPLE OF COTTON RESEARCH IN SENEGAL

The Senegalese Institute for Agricultural Research (ISRA) began its current research activities on the cotton sub-sector in 1985/86. The research program includes three components: breeding, agronomy, and crop protection.

- Crop breeding has focused on agronomic yield increases, fiber quality and ginning results. The sequence of new varieties produced by the program can be summarized as follows:

Variety	**Introduction**
IRMA 9697	1986
IRMA 1243	1988
STAM F	1992
STAM 42	1993

- Agronomic research has resulted in new fertilizer formulas and use rates. The orginal NPK formula (8-18-27) was replaced by 6-14-35 in 1986, then by 14-23-14 and finally by 20-16-20. The recommended urea level was maintained at the level of 50 kg per hectare, but the use of potassium chloride at the level of 100 kg per hectare was discontinued in 1986.

- Crop protection research in phytotechny and entomology has also produced significant improvements. The herbicide CALIFOR G replaced the COTODON MIX and the insecticide treatments of Very Low Volume, i.e., 1 liter of commercial product per hectare, were generalized.

Taken together, the agronomic and crop protection improvements have decreased production costs by about 13,000 FCFA per hectare. The agronomic (seed cotton) and industrial (fiber) yield gains from research have also yielded significant economic gains. In 1993, to analyse and document the combined effects of their cotton research programs, ISRA initiated a major impact assessment activity. The methods and results used in that study are reported in this manual through a series of boxes. Readers can also retrace each step of the impact assessment process, creating each formula themselves, by working through the third computer exercise using the spreadsheet entitled “example3.wk1".

Impact assessment methods

Impact assessments can generally be divided into two categories:

- *ex-post* studies, for technologies already being used, and
- *ex-ante* studies, for technologies not yet adopted.

In both cases, some of the data required to measure impacts can be directly observed, and other data must be estimated indirectly from other evidence. This manual covers the appropriate sources and uses of data for both cases. Choosing and using data is perhaps the single most important skill required in impact assessment. Ex-post impact assessments in which actual surveys are used can be much more reliable than ex-ante assessments, which must rely on researchers' trials and extrapolations. But in both cases, the difference between successful and unsuccessful impact assessments typically rests on the judgment of the researchers in collecting and interpreting their data.

Field data can be used to do impact assessments using a variety of methods. Generally these are divided into three main groups:

- econometric approaches, aimed at estimating the marginal productivity of research over a long time period and a variety of research activities;

- programming methods, aimed at identifying one or more optimal technologies or research activities from a set of options; and

- economic surplus methods, aimed at measuring the aggregate social benefits of a particular research project.

Although all three methods are in widespread use, the third is the most popular. It requires the least data, and can be applied to the broadest range of situations. It is also an approach for which the basic techniques can be grasped with a minimum of training. It is therefore the method we propose to use in this manual; brief reviews of the other two methods are also provided in the conclusion.

Organization and use of the manual

This first section of the guidebook is intended to introduce the concept of impact assessment; the second explains the economic surplus method. This is followed by a detailed discussion of practical guidelines for the collection and use of field data. Finally, a brief conclusion puts the economic surplus method into perspective, relative to other possible impact-assessment techniques.

Throughout the guidebook, shaded boxes are used to follow the application of impact assessment techniques to an important real-life example: measuring the impact of Senegalese research on cotton. This case study was chosen because it covers many of the issues likely to be encountered in other impact studies. As noted in Box 1 above, Senegal's cotton research program involved improvements in all three key aspects of the production system: input costs, crop yields, and processing. Senegal's research program also produced a sequence of identifiable new techniques, not just a single one. In this way, the Senegal case study provides a rare opportunity to illustrate a range of ideas with a single example.

Senegal's case study is interesting but quite complex. Simpler examples are given in the self-paced computer exercises. After reading the manual, the reader is encouraged to try applying these techniques themselves, starting with a relatively simple hypothetical case using the spreadsheet entitled "example1.wk1". This file can be retrieved into any spreadsheet software. It contains all the data needed for a complete analysis, and contains blank cells in which the required formulas can be entered to retrace all the steps detailed in the manual, following Sections 4 and 5. Readers may check their work by comparing their results to those printed in the manual's appendix. Readers may also compare their formulas to those entered in the completed spreadsheet, "complete1.wk1".

Once readers have completed the first exercise, they should attempt the second, by entering the appropriate formulas in the "example2.wk1" spreadsheet, proceeding as before. This example uses real data, from a recent study of sorghum research in Cameroon. The innovation in this case is a variety which is relatively drought-tolerant. For this reason, the impact assessment must consider the impact of rainfall levels on yields, and the exercise shows one way in which this can be done. Again, readers can check their work by comparing the results to the appendix of this manual, and comparing the formulas to those in the spreadsheet "complete2.wk1".

Finally, readers who have successfully completed the first two examples are ready to attempt the relatively complicated case of cotton research in Senegal. The data are presented in "example3.wk1", while the formulas needed to reproduce the data given in the text boxes is given in "complete3.wk1". After completing all three spreadsheet exercises, readers will have both the computer and analytical skills needed to do their own analyses, as well as guidelines for collecting their own data.

THE ECONOMIC SURPLUS METHOD

The main thrust of an impact assessment analysis is to compare a situation *without* research, against an alternative situation *with* research. This should not be confused with a *before* and *after* comparison. Since conditions are constantly changing, before/after comparisons can be very misleading.

For example, in many settings crop yields could decline over time, due to the depletion of nutrients or the build-up of pathogens. Innovation is needed to permit continued cultivation without yield loss. In this situation, a before/after comparison might find that research is not valuable because it does not result in rising yields. But in fact the research is valuable, because it prevents yields from falling, and may even prevent the land from going out of production entirely. Thus impact assessments must be based on carefully constructed scenarios of the situations with and without research. Comparisons of the situation before and after research may be interesting, but they cannot be considered to be valid economic impact assessments.

The economic surplus method provides a relatively simple, flexible approach to specifying the value of research, by comparing the situations with and without it. In order to turn agronomic data into economic values, the surplus approach uses the concepts of *supply, demand* and *equilibrium.* “Supply” represents producers’ production costs, and “demand” represents consumers’ consumption values. Some “equilibrium” quantity and price results from the interaction of these two forces. Economic welfare depends not only on the equilibrium price and quantity (which may be directly observed in the market), but also on the producers’ production costs and consumers’ consumption values (which must be imputed from their actions).

Supply and production costs

The economic surplus approach begins by recognizing that production levels depend on the use of a wide range of inputs: primarily land and labor, but also livestock, manure, fertilizers, seeds, and possibly chemicals. Each of these has a cost to the producer. The higher the price (or value) of the product, the more inputs it is worthwhile to use, and the higher is the level of production. A higher product price will bring more inputs onto each hectare, and more hectares under the crop.

Mathematically, we can write the influence of production costs on production levels in a simple function, known as a “supply curve”:

$$P_s = f_s(Q_s)$$

An example of a supply curve is shown on Graph 1. It slopes upward, showing that increases in the "supply price" (P_s) of a good are linked to increases in the "quantity supplied" (Q_s). In other words, the supply curve indicates that it is not possible to raise production levels without raising the price paid, unless something else changes to "shift" the supply curve. Such a "supply shift" could be anything that changes the costs of production, such as a change in the value of important inputs such as labor or land--or a change in production methods, such as the use of a new crop variety.

Supply curves can take different shapes, as discussed later in this manual (Section 5.1). But for many purposes, it is appropriate to consider the curves to be straight lines. Thus, the supply curve takes the following form:

$$P_s = a_s + b_s Q_s$$

This is line (a "linear" curve), of slope b_s and intercept a_s.

Demand and consumption values

As with supply, the economic surplus approach to demand begins by recognizing that quantities consumed depend on prices paid: at a higher price people generally consume less, because they may switch to other goods, and their income may be more quickly exhausted. Mathematically, we can illustrate this idea with a "demand curve",

$$P_d = f_d(Q_d)$$

an example of which is also shown on Graph 1. The demand curve slopes down, capturing the idea that increases in the "demand price" (P_d) are linked to decreases in the "quantity demanded" (Q_d). Thus, it is not possible to raise consumption quantities without lowering the price paid, unless something else changes to "shift" the demand curve. Such a demand shift could be anything that changes consumers' willingness and ability to pay for the good, such as a change in income, preferences, or the prices of important substitute goods. Demand curves can take different shapes, as discussed in Section 5.1, but it is often appropriate to consider them straight lines. Thus the demand curve takes the following form:

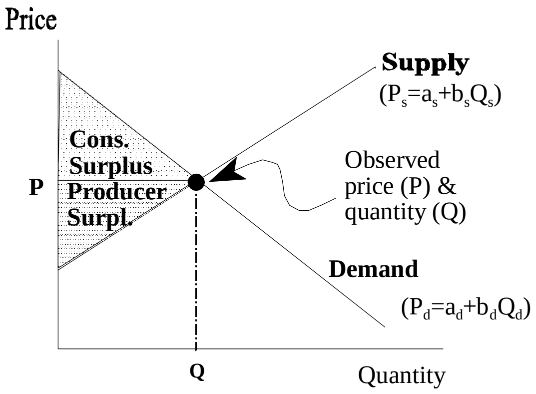
$$P_d = a_d + b_d Q_d$$

Equilibrium and economic surplus

To complete the economic surplus approach, we note that the observed levels of quantities produced must be some “equilibrium” between supply and demand. This may be a very temporary equilibrium, which will change as soon as there is a shift in the supply and demand curves. But at each point in time, for some particular location or region, there is a single quantity (Q) that is both supplied (Q_s) and demanded (Q_d), as well as a single price (P) that is both paid to suppliers (P_s) and received by demanders (P_d).

The prices and quantities which we observe in surveys are important indicators of the economic situation, but producers and consumers are actually concerned with their entire supply and demand curves--not just the current equilibrium points along those curves. In general, we can estimate the social value of a given production and consumption level using the concept of the “economic surplus”, defined as the area between the supply and demand curves.

Figure 1.
Supply, demand and economic surplus



On Figure 1, area is measured in tems of money (price on the vertical axis, times quantity on the horizontal axis). Economic surplus is thus the value of production and consumption, in monetary terms. It the money value that consumers would have paid for each unit consumed, minus the monetary value that producers would have paid for each unit produced, up to the actual market price and quantity.

Economic surplus is not, of course, a monetary value that can be measured in anyone’s bank account. It circulates throughout the economy, representing consumers’ well-being from the consumption of this and other goods. The surplus earned in one market is quickly spent in another. As shown in Figure 1, total economic surplus can be divided into two parts: “consumer surplus” (area between the demand curve and the market price), and “producer surplus” (area between the supply curve and the market price). For most impact assessments, however, we are concerned mainly with the total surplus, or area between the supply and demand curves.

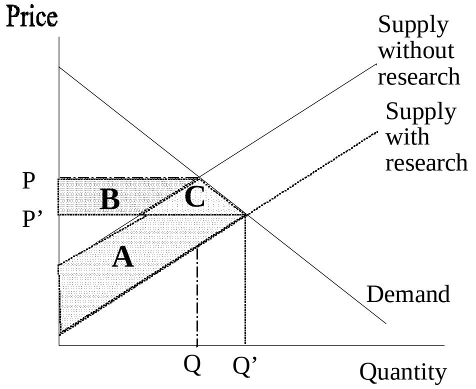
The impact of research on economic surplus

The purpose of the supply and demand curves is simply to establish clear scenarios for what would happen with or without research; economic surplus permits us to evaluate the difference between those two situations using a single measure. Any change in economic surplus is a measure of the social benefits derived from research. It is these gains that we intend to measure.

As pictured in Figure 1, economic surplus is the region between the supply curve and the demand curve. How can research affect economic surplus? Given these supply and demand curves, the equilibrium point is also the point of maximum total surplus. At smaller quantities (to the left of Q), some additional economic surplus would be attainable by expanding production. At larger quantities (to the right of Q), economic surplus would be increased by reducing production. Thus, only the observed point is optimal, in the sense of providing the maximum amount of economic surplus. However, it is possible to obtain additional benefits by shifting the supply or demand curves. Research does this by providing some innovation, enabling producers to supply a larger quantity at the same price, or to supply the same quantity at a lower price.

Figure 2 illustrates the impact of a successful research effort on the supply curve, the equilibrium price and quantity, and economic surplus. The innovation shifts the supply curve down and to the right. This shift in supply moves the equilibrium to a lower level of price (P') and a higher level of quantity (Q').

Figure 2.
Impact of research on economic surplus



For producers, the impact of research is to reduce production costs; in terms of economic surplus this is represented by an increase of area A (the area between the with- and without-research supply curves, under the P' price line). But research also reduces the price received by producers, which reduces producer surplus by area B (the area between the two price lines, above the without-research supply curve). Thus the net change in producer surplus is the gain of area A, minus the loss of area B.

It turns out that producers' net gain (A-B) is positive only when the demand curve is relatively flat, or "elastic". In this situation, the increased quantity demanded outweighs the lower price, and producers' economic surplus is raised by adopting the research results. However, when consumer demand is relatively steep or "inelastic", only a limited quantity of a good is wanted, and technical change actually hurts producers. In this situation, the price-reduction effect of research outweighs the quantity-increasing effect, so producers as a whole actually lose from adopting the research results.

For consumers, the effect of research is always a gain. They receive whatever was lost by producers due to lower prices (area B), plus the economic surplus on the increased quantity (area C). It is the consumers' net gain (B+C) which leads to our earlier argument that, in general, it is consumers who benefit the most from research on staple foods (whose demand is relatively inelastic, with a steep demand curve), while producers benefit the most from research on export crops (whose demand is relatively elastic, with a flat demand curve). In fact, we often observe producers or marketing groups subsidizing research into export crops, while research on staple foods is more often financed by taxpayers through the government.

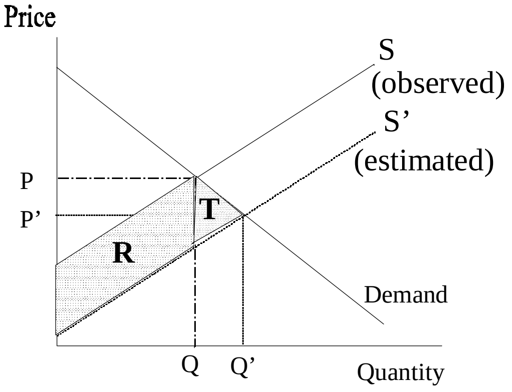
For the economy as a whole, the impact of research is a gain of area A plus area C. The area B is gained by consumers but lost by producers, so it does not represent a net gain to the whole economy. Area C can be considered to be the benefits of reducing the good's consumer price (from P to P'), while area A may be considered to be the benefits of reducing the good's production costs (from one supply curve to the other). The sum of the benefits (A+C), is often known as the "social gain" from research; the objective of this manual is to provide simple techniques for estimating that net social gain, using readily available data.

Measurement of social gains

To estimate the social gain in practice, it is most convenient to divide it in a different way than Figure 2, into the region between the two supply curves from the origin to the without-research quantity (Q), and a triangle between the with- and without-research quantities (Q and Q'). Exactly how that triangle should be defined depends on whether one is conducting an ex-ante study of technologies not yet being used, or an ex-post study of technologies that have already been adopted. These two alternatives are illustrated in Figures 3 (for an ex-ante study) and 4 (for an ex-post analysis).

Figure 3 illustrates a situation in which the research results have not yet been adopted, so the observed quantity and price are on the without-research supply curve (Q, P). The job of th impact assessment is to estimate the unobserved

Figure 3.
An ex-ante impact assessment



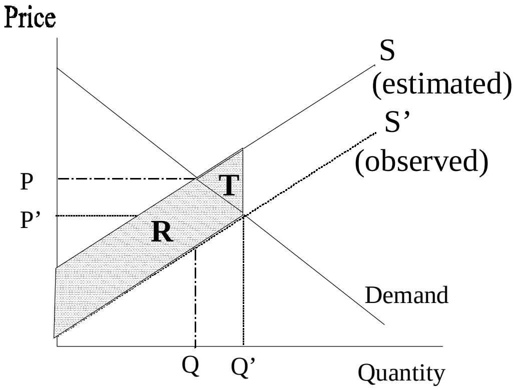
situation with research (Q', P'). In this case, the total social gain that we seek to measure is a parallelogram or rectangle (area R) plus a triangle (area T).

Dividing net social gains into areas R and T illustrates how most of the benefits from research typically arise from reduced production costs (a lower supply curve), rather than increased production levels. The value of cost reductions at the without-research level of production (Q) is shown by area R, while the social benefits from increased production (from Q to Q') are shown by area T. Area R is almost always much larger than area T, demonstrating that the gains from research should not be measured in terms of increased production levels. Lower production costs are usually of more economic value.

As suggested by Figure 3, most of the difficulty in impact assessment lies in estimating the height of area R, and hence the magnitude of the supply shift. But before addressing this issue, it is important to note that most impact assessments are not ex-ante studies as illustrated in Figure 3; they are ex-post studies, of technologies that have already been adopted by some producers. In the case of ex-post studies, we would have a somewhat different situation. There, the observed quantity and price already include the effects of research. It is the with-research equilibrium (Q', P') that is observed, while the without-research situation (Q,P) must be estimated through the impact assessment.

The case of an ex-post assessment is illustrated in Figure 4. In this situation, the total social gain we wish to measure is area R (which in this case includes area T), minus area T. Area R represents the social gain due to the reduction in production costs at the observed level of production (Q'), while area T represents a correction for the change in quantity caused by the research.

Figure 4.
An ex-post impact assessment



As illustrated in Figures 3 and 4, impact assessments using the economic surplus approach are based on estimating the magnitude of cost reductions given the observed level of output (i.e. area R), and then making an adjustment for the change in quantity associated with a change in price (i.e. area T). The height of area R is generally the most important determinant of the impact assessment results. How, then, can it be estimated?

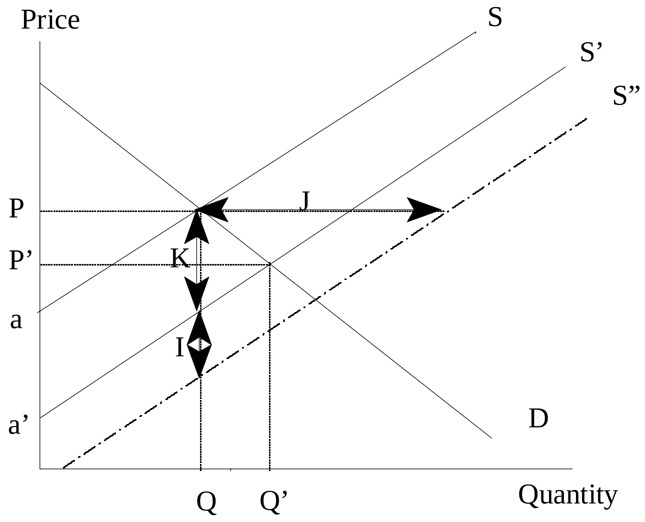
The height of area R is measured in terms of money per unit of output. Typically, the effects of research are observed in terms of quantity of output per unit of input, such as an increased crop yield per acre. For a given cost of inputs, increased quantities represent a *horizontal* shift of the supply curve. But the adoption of research results may require some investment in new inputs. For a given level of output, this increased cost represents a *vertical* shift. What is necessary, therefore, is to combine data on changing quantities (a horizontal shift) and changing input costs (a vertical shift), to obtain a net shift in terms of costs per unit of output.

Figure 5 shows how these various types of data can be combined in a typical impact assessment. It illustrates the case of a successful research project, which raises output for a given set of inputs by the quantity J, from supply curve S to the line marked S". Typically, the relevant data are observed in terms of yields per hectare (e.g. kg/ha). To obtain a J parameter, whose units are total quantities (e.g. kg), we must multiply the yield gain per hectare (in kg/ha) times the area planted with the new technique (ha). For example, if yields with a new technique are 100 kg/ha higher than they are without it, and 1,000 hectares are planted with it, then J would be 100,000 kg (=100 kg/ha x 1,000 ha).

If the new technique could be adopted at no cost, then the S” (S+J) curve would be the with-research supply curve. However, adoption typically requires some investment in new inputs. Farmers may have to purchase certified or hybrid seeds or fertilizer, or use more labor in their operations. The vertical distance I represents those “adoption costs” on a per-unit basis (e.g. $/kg). Typically, the relevant data are observed in terms of some additional costs per hectare (e.g. kg/ha). To obtain the relevant I parameter, adoption costs per hectare must then be divided by the average yield over all hectares (in kg/ha) in production. For example, if costs per hectare with the new technique are $50 higher than without it, and average yields are 500 kg/ha, then the per-unit adoption costs of the new technique is $0.10 per kg (= 50 $/ha ÷500 kg/ha). Note that the average yield should be the average for all hectares, not just those under the new technique.

Taking both J and I into account leads to a net shift in the supply curve from S (without research) to S' (with research). The vertical distance K represents the net gain, in terms of a decrease in production costs. It is the height of area R in Figures 3 and 4, or vertical shift in the supply curve, and is often known as the “shift” or “K” parameter.

Figure 5.
Estimating supply shifts using observed data



Mathematical formulas for calculating social gains
In Figures 3-5 above, the supply curve *could* have taken any form (a straight line or a curve), but for simplicity we assumed it to be a straight line. Similarly, the shift in the supply curve can take many different forms. But practical purposes, it is appropriate to assume that technical change produces a *parallel* shift, i.e. an equal cost reduction at each possible level of production. Thus, in Figure 5, the shift parameter K is also the difference between the vertical intercepts of the two supply curves (a and a’).

The shape of the demand and supply curves and the type of the supply shift determine what mathematical formula is needed to calculate the net social gain. For this manual, we use a linear curve and a parallel shift in part because it is the appropriate specification for many situations, but also because it is the specification for which the relevant formulas are easiest to derive. It is therefore appropriate to begin with this simplest case, and then move on to other specifications as needed.

For the case of a parallel shift with linear supply and demand curves, the social gain (SG) can be expressed as area R, plus or minus area T. R is a paralellogram, whose area is its height times its length. T is a triangle of the same height, whose base is the change in quantity caused by research.

The precise formulas for estimating the area of the social gain, and each of the individual parameters used in that estimation, are given in the following formula boxes (Box A through F). The formulas are then applied to the Senegal example, in the case-study boxes (Box 1 through 5).

BOX A. ESTIMATING THE SOCIAL GAINS FROM RESEARCH

To move from the graphical approach presented in the text to practical application, it is necessary to derive specific mathematical formulas corresponding to each graph. The "Formula Boxes" (Box A through F) detail the origin and significance of the required formulas, along with the source and nature of each variable used in the estimation process.

To estimate the social gains illustrated in Figures 3 and 4, we need the formula for the area of a parallelogram, plus or minus the area of a triangle. Defining the variable Q to be the *observed* quantity produced, ΔQ to be the change in quantity caused by research (i.e. Q-Q' in ex-ante studies, or Q'-Q in ex-post analyses), and K to be the vertical shift in supply, then we have the social gains expressed in the following simple formula, using addition in ex-ante studies and subtraction in ex-post analyses:

$$SG = KQ \pm \tfrac{1}{2}K\Delta Q$$

Note that Q is directly observable, through a census of agriculture or estimates published by a national statistics office or ministry of agriculture. The unknown variables, which must be estimated in the impact assessment, are K and ΔQ. In order to calculate these values, we will first need to estimate J and I.

The parameters J, I, K and ΔQ are not directly observable, but can be estimated using available data. In particular, we will need estimates of the results of research, in terms of yield increases (ΔY), adoption costs (ΔC), adoption rates (t), total acreage planted to the crop (A), total production (Q) and the overall average yield ($Y = Q/A$). The following boxes detail a straightforward approach to computing and using these variables.

BOX B. ESTIMATING PRODUCTION INCREASES: THE J PARAMETER

The J parameter can be defined as the total increase in production that would be caused by adopting the new technology, in the absence of any change in costs or price. It can readily be estimated on the basis of three kinds of observable data:

- the yield increase (ΔY) caused by adopting the new technology, expressed in terms of physical units (e.g. kg/ha);
- the adoption rate (t), expressed as the proportion of total area under the new technology;
- the total area (A) in the crop (often measured in ha).

Thus we have:

$$J = \Delta Y \times t \times A$$

Note that the adoption rate in terms of area planted may be very different from the adoption rate in terms of the number of farmers, since different farmers plant different areas. It is essential to try to estimate adoption carefully, using the best possible information on area planted.

For many applications, it is more practical to compute the J parameter in proportional terms,as the increase in quantity produced as a share of total quantity:

$$j = J/Q$$

This transformation permits us to estimate the supply shift parameter (j) in terms of the yield gains, adoption rates, and the overall average yield level (Y):

$$j = (\Delta Y \times t) / Y$$

Note that this simplified formula is valid only if the denominator (Y) is defined as the overall average yield level (Y=Q/A). It is often convenient to check the consistency of this sort of formula with the units of analysis. For example, in this formula we have:

$$j = J(kg)/Q(kg) = \Delta Y(kg/ha) \times t / Y(kg/ha)$$

Since all the units cancel out, this formula is consistent with calculating a ratio.

BOX C. ESTIMATING ADOPTION COSTS: THE I PARAMETER

The I parameter may be defined as the increase in per-unit input costs required to obtain the given production increase (J). It can be calculated on the basis of the following parameters:

- the adoption costs (ΔC), per unit of area switched to the new technology;
- the adoption rate (t), in terms of area; and
- the overall average yield (Y).

The complete formula is:

$$I = \Delta C \times t / Y$$

Typically, the units involved might be:

$$(\$/kg) = (\$/ha) / (kg/ha)$$

Often it is more convenient to do our calculations in proportional terms, as the increase in production costs (I) as a share of the observed product price (P). This proportional cost-increase parameter (c) is:

$$c = I/P = (\Delta C \times t) / (Y \times P)$$

A unit analysis yields:

$$c = \frac{I\ (\frac{\$}{kg})}{P\ (\frac{\$}{kg})} = \frac{\Delta C\ (\frac{\$}{ha}) \times t}{Y\ (\frac{kg}{ha}) \times P\ (\frac{\$}{kg})}$$

Once more the units cancel out indicating that c is a proportion without units.

BOX D. ESTIMATING SUPPLY SHIFTS: THE K PARAMETER

The K parameter may be defined as the net reduction in production costs induced by the new technology, combining the effects of increased productivity (J) and adoption costs (I). It corresponds to a vertical shift in the supply curve, given J and I, and could be computed using the slope of the supply curve (b_s) as follows:

$$K = [J \times b_s] - I$$

In practice, the slopes of supply curves (b_s) are not generally used in calculations, because they are associated with specific units of measurement. Researchers prefer to use the supply elasticity (ε), which is independent of the units of measurement:

$$\begin{aligned} \varepsilon &= \%\Delta Q / \%\Delta P \\ &= (\Delta Q/Q)/(\Delta P/P) \\ &= (\Delta Q/\Delta P) \times (P/Q) \\ &= (1/b_s) \times (P/Q) \\ b_s &= \varepsilon \times Q/P \\ K &= J/(\varepsilon Q/P) - I \\ &= [JP/\varepsilon Q] - I \end{aligned}$$

Using proportional terms (i.e. the net reduction in production costs as a proportion of the product price), we have:

$$\begin{aligned} k &= K/P \\ &= [JP/\varepsilon QP] - I/P \\ &= (j/\varepsilon) - c \end{aligned}$$

This formulation shows clearly that, when supply is “inelastic” (ε is less than 1), then the elasticity amplifies the k-parameter ($k > j-c$). In this case, a given yield increase caused by research has a relatively high economic value--perhaps because there is little available land on which to expand production. On the other hand, when supply is "elastic" (ε is greater than 1), perhaps because land is abundant, then the elasticity dampens the k parameter ($k < j-c$). This corresponds to a situation in which it is relatively easy to expand production, so the gains from research have a relatively low economic value.

BOX E. ESTIMATING EQUILIBRIUM QUANTITY CHANGE: ΔQ

The change in quantity actually caused by research (ΔQ) depends on the shift in supply and the responsiveness of supply and demand. The equilibrium situation without research would be that price and quantity which satisfy both demand and supply:

$$
\begin{aligned}
& Q_s = Q_d \\
& a_d + b_d P = a_s + b_s P \\
& P = (a_s - a_d)/(b_d - b_s)
\end{aligned}
$$

With research, the equilibrium must be on a new supply curve, that is shifted in the direction of a price increase:

$$
\begin{aligned}
& Q'_s = Q_d \\
& a_d + b_d P' = a_s + b_s K + b_s P' \\
& P' = (a_s - a_d + b_s K)/(b_d - b_s)
\end{aligned}
$$

The resulting change in price is:

$$
\begin{aligned}
\Delta P \quad & = -b_s K/(b_d - b_s) \\
& = b_s K/(b_d + b_s)
\end{aligned}
$$

And hence the change in quantity is:

$$
\begin{aligned}
\Delta Q \quad & = b_d \Delta P \\
& = b_d b_s K/(b_d + b_s)
\end{aligned}
$$

To substitute elasticities for slopes, we need the elasticity of demand (*e*), expressed in absolute value:

$$
\begin{aligned}
e \quad & = \%\Delta Q/\%\Delta P \\
& = (\Delta Q/Q)\times(\Delta P/P) \\
& = (\Delta Q/\Delta P)\times(P/Q) \\
& = b_d \cdot (P/Q) \\
b_d \quad & = e/(P/Q) = eQ/P
\end{aligned}
$$

Thus:

$$
\begin{aligned}
\Delta Q \quad & = (eQ/P)\times(\varepsilon Q/P)K/[(eQ/P)+(\varepsilon Q/P)] \\
\Delta Q \quad & = e\varepsilon K(Q^2/P^2)/[(e+\varepsilon)\times(Q/P)]
\end{aligned}
$$

In proportional terms, this simplifies to:

$$
\Delta Q \quad = Qe\varepsilon k/(e+\varepsilon)
$$

BOX 2: ESTIMATING SUPPLY SHIFTS IN SENEGAL

In this box we demonstrate the step-by-step calculation of supply shifts and price changes due to the adoption of new varieties and agronomic treatments for cotton in Senegal, providing all of the data and formulas on a step-by-step basis.

The estimation of social gains begins with a review of some basic data on Senegal's cotton sector. Table 2.1 shows clearly that, although there may be a small upward trend in seed cotton yields, an more important trend has been increasing yields of cotton fiber.

Table 2.1 Market data for cotton in Senegal

Year	Acreage (ha) (A)	Prod'n. (mt) (Q)	Yield (kg/ha) (Y)	Percent Fiber
1971	13 618	11 832	869	35.3
1976	39 206	30 685	783	37.1
1977	43 845	45 208	1031	37.1
1978	47 109	37 166	789	35.9
1979	48 299	33 806	700	37.4
1980	30 908	26 868	869	36.0
1981	29 913	20 607	689	35.1
1982	31 977	41 007	1282	37.2
1983	42 018	47 081	1120	39.1
1984	33 353	30 461	913	38.6
1985	46 337	46 913	1012	40.4
1986	38 848	27 942	719	39.0
1987	25 482	26 871	1055	39.9
1988	28 878	38 816	1344	39.5
1989	38 558	38 703	1004	40.0
1990	24 183	29 303	1212	41.5
1991	43 341	44 723	1032	40.7
1992	44 164	50 577	1145	40.1
1993	44 772	47 536	1072	40.2

Box 2, page 1 of 8

Estimating the j-parameter

Recall the formula to use:

$$j = J/Q = (\Delta Y \times t) / Y$$

To estimate j, we need ΔY, t and Y. The variable Y, representing the overall cotton yield, is available directly from Table 2.1. The other two elements must be estimated separately.

Computing the increased yield (ΔY)

ISRA begun its cotton research program in 1983. From 1985 to 1993, four improved varieties of cotton were validated by ISRA and adopted by producers. We wish to assess the cumulative impact of all these changes, relative to the previous BJA variety and associated agronomic inputs. Thus we will need to add up yield increases from several varieties, to obtain the total increase in yield for each year the period from 1985 to 1993.

Table 2.2 Yield gains for cotton in Senegal

Improved variety	(Years of release)	Yield Gain over BJA (kg/ha)	Cumulative Yield Gain (kg/ha)
L299	(1980-88)	78	78
I9697	(1985-90)	194	272
I1243	(1989-94)	(2)	270
STAM F	(1992-94)	62	332
STAM 42	(1993-94)	24	356

To use the agronomic data from the previous table as a yield-increase parameter (ΔY) in our formulas, we will need to identify the specific yield increases achieved in each year, as in the table below.

Table 2.3 Value of ΔY for cotton in Senegal (kg/ha)

Year	L 299	I 9697	I 1243	STAM F	STAM 42
1980	78				
1981	78				
1982	78				
1983	78				
1984	78				
1985	78				
1986	78	272			
1987	78	272			
1988	78	272			
1989		272	270		
1990		272	270		
1991			270		
1992			270	332	
1993			270	332	356
1994			270	332	356

Calculating the adoption rate (t) for each new variety

The adoption rate parameter (t) is defined as each year's acreage planted to each variety, divided by the total area planted to all varieties. These data are presented in Table 2.4, as reported by the extension service for the national cotton company, SODEFITEX. Note that in this context, area planted is reported with relatively great accuracy, because sales of seeds and other inputs are tightly controlled. For crops where seeds do not have to be purchased every year, adoption rates must be estimated through farm surveys.

Despite the relative accuracy of area figures for cotton, note that there are small differences between the data in Table 2.4 (for the sum of the areas planted to each variety) and in Table 2.1 (for the total area planted to cotton). In principle these data should be identical, but errors in reporting and transcription cause data from different sources to differ.

Box 2, page 3 of 8

Table 2.4 Area planted (A) by variety in Senegal (ha)

YEAR	Total Acreage	BJA	L 299	I 9697	I 1243	STAM F	STAM 43
1980	30 908	30532	376				
1981	29 899	29781	118				
1982	31 776	29376	2400				
1983	42 018	16246	25772				
1984	33 357	10230	23058				
1985	46 350		46337	13			
1986	38 849		38594	255			
1987	25 483		20121	5362			
1988	28 878		44	28834			
1989	38 590			36735	1855		
1990	24 183			8766	15417		
1991	35 526				35526		
1992	44 164				44075	89	
1993	44 772				43661	1106	5
1994	42 745				28450	14189	106

Using the adoption data above, we can calculate the adoption rate for each variety by dividing the area in each variety by the total area planted (column 1), resulting in:

Table 2.5 Adoption rate (t) by variety in Senegal (proportion of total area)

YEAR	BJA	L 299	I 9697	I 1243	STAM F	STAM 43
1980	. 988	. 12				
1981	. 996	. 004				
1982	. 924	. 076				
1983	. 387	. 613				
1984	.309	. 691				
1985		1.000	. 000			
1986		. 993	. 007			
1987		. 790	. 210			
1988		. 02	. 998			
1989			. 952	. 048		
1990			. 362	. 638		
1991				1.000		
1992				. 998	. 002	
1993				. 975	. 025	. 000

Box 2, page 4 of 8

Calculating the proportional production-shift parameter (j)

The next step in the estimation process is to calculate the proportional shift in production (j), using the formula:

$$j = J/Q = (\Delta Y \times t) / Y$$

The elements of this formula are provided in Table 2.3 (for ΔY), Table 2.5 (for t) and Table 2.1 (for Y). Inserting these values into the formula yields:

Table 2.6 Proportional production shifts (j) in Senegal

Year	L 299	I 9697	I 1243	STAM F	STAM 42	TOTAL L
1980	0. 001					0. 0011
1981	0. 000					0. 0004
1982	0. 005					0. 0046
1983	0. 043					0. 0427
1984	0. 059					0. 0591
1985	0. 077					0. 0771
1986	0. 108	0. 002				0. 1103
1987	0. 058	0. 054				0. 1126
1988	0. 000	0. 202				0. 2022
1989		0. 258				0. 2579
1990		0. 081	0. 142			0. 2234
1991			0. 262			0. 2616
1992			0. 235	0. 001		0. 2359
1993			0. 246	0. 008	0	0. 2533

Calculating the per-unit adoption cost parameter (c)

To calculate the cost associated with increasing production, we use the formula:

$$c = I/P = (\Delta C \times t) / (Y \times P)$$

Here we need two additional sets of data: the per-hectare difference in costs (ΔC), and the product price (P).

Box 2, page 5 of 8

Calculating adoption costs per hectare (ΔC)

The cost of adopting each new technology is the change in production costs, relative to the unimproved technology. ISRA's research has significantly reduced these adoption costs, so that each new improved package is less costly to adopt, relative to unimproved methods. The approximate cost of production using unimproved methods is a constant 30 000 FCFA per hectare, in nominal terms. Table 2.7 below shows the declining level of costs for the improved package, the declining difference in costs between the improved and unimproved packages, and the cost difference (ΔC) in real terms, after division by the price index.

Table 2.7 Adoption costs per hectare (ΔC) in Senegal (FCFA/ha)

Year	Input costs for the improved package (FCFA/ha)	ΔC nominal (FCFA/ha)	Consumer Price Index (base: 1993=1)	ΔC real (FCFA/ha)
1985	50 000	20 000	1. 027	19 474
1986	47 257	17 257	1. 089	15 847
1987	47 257	17 257	1. 044	16 530
1988	47 257	17 257	1. 025	16 836
1989	42 412	12 412	1. 030	12 050
1990	42 412	12 412	1. 033	12 015
1991	41 936	11 936	1. 015	11 760
1992	41 936	11 936	1. 015	11 760
1993	41 936	11 936	1. 000	11 936

Calculating the product price in real terms (P)

In this table the nominal price is adjusted for inflation by using the Consumer Price Index.

Table 2.8 Product prices (P) in Senegal (FCFA/kg)

Year	Nominal Price (FCFA/kg)	Consumer Price Index (base: 1993=1)	Real Price (P)
1985	69.4	1.027	67.58
1986	99.6	1.089	91.46
1987	99.8	1.044	95.59
1988	99.7	1.025	97.27
1989	99.7	1.030	96.80
1990	99.8	1.033	96.61
1991	99.9	1.015	98.42
1992	100.0	1.015	98.52
1993	99.2	1.000	99.20

Calculating the proportional adoption cost (c)

The proportional increase in costs caused by adopting the improved packages is obtained using the results from Table 2.7 (ΔC), Table 2.5 (t), Table 2.1 (Y), and Table 2.8 (P), with the formula:

$$c = I/P = (\Delta C \times t)/(Y \times P)$$

Table 2.9 Proportional adoption costs (c) in Senegal

Year	L 299	I 9697	I 1243	STAM F	STAM 42	TOTAL
1985	0. 28469	0. 00008				0. 28477
1986	0. 23940	0. 00158				0. 24098
1987	0. 12941	0. 03449				0. 16390
1988	0. 00020	0. 12859				0. 12879
1989		0. 11804	0. 00596			0. 12400
1990		0. 03720	0. 06542			0. 10261
1991			0. 11577			0. 11577
1992			0. 10403	0. 00021		0. 10424
1993			0. 10946	0. 00277	0. 00001	0. 11224

Calculating the net shift in the supply curve (k)

To combine the data on increased production (j) and adoption costs (c) into the net supply-shift parameter (k), we need only one new parameter: the supply elasticity (ε). Given the relatively little expansion potential of cotton, a low value (e.g. $\varepsilon = 0.3$) is appropriate, and we obtain the results of Table 2.10 using the formula:

$$k = K/P = [JP/\varepsilon QP] - I/P = (j/\varepsilon) - c$$

Table 2.10 Proportional supply shifts (k) in Senegal

Year	j	ε	c	k
1985	0. 0771	0.3	0. 28477	-0. 02792
1986	0. 1103	0.3	0. 24098	0. 12653
1987	0. 1126	0.3	0. 16390	0. 21152
1988	0. 2022	0.3	0. 12879	0. 54508
1989	0. 2579	0.3	0. 12400	0. 73565
1990	0. 2234	0.3	0. 10261	0. 64195
1991	0. 2616	0.3	0. 11577	0. 75632
1992	0. 2359	0.3	0. 10424	0. 68215
1993	0. 2533	0.3	0. 11224	0. 73210

Calculating the change in quantity (ΔQ) due to research

Our final step in this part of the impact assessment is to compute the change in equilibrium quantity that is induced by the research, following the formula:

$$\Delta Q = Q e \varepsilon k/(e+\varepsilon)$$

Note that, to obtain (ΔQ) in terms of kilograms, it is necessary to multiply the figures for total production (Q) in Table 2.1 by 1000. Also, we must choose a value for the demand elasticity (*e*, expressed in absolute value): since changes in Senegal's quantity produced will have little effect on the price received, we use a relatively large level (*e* = 10). This level of elasticity would be appropriate for most goods that are traded internationally. Products which are sold only in a local market, such as millet or cassava, might would have an elasticity of demand below one.

Table 2.11 Changes in equilibrium quantity (ΔQ) in Senegal (kg)

Year	Q (kg)	e	ε	k	ΔQ (kg)
1985	46 913 000	10	0.3	-0.02792	-381 530
1986	27 942 000	10	0.3	0.12653	1 029 738
1987	26 871 000	10	0.3	0.21152	1 655 453
1988	38 816 000	10	0.3	0.54508	6 162 512
1989	38 703 000	10	0.3	0.73565	8 292 749
1990	29 303 000	10	0.3	0.64195	5 478 981
1991	44 723 000	10	0.3	0.75632	9 851 891
1992	50 577 000	10	0.3	0.68215	10048 796
1993	47 536 000	20	0.3	0.73210	10136 290

Box 2, page 8 of 8

☞ Recap of the key formulas for evaluating social gains

Table 1 summarizes the sequence of computation for the parameters needed in evaluating the social gains from research, along with the definition of each parameter, its formula, and the data needed for its computation.

Table 1. Recap of key formulas

STEPS	DEFINITION	FORMULA	DATA & TYPICAL UNITS
1. Computing j	Change in production due to the new technology, as a proportion of total production	$j = \frac{(\Delta Y \times t)}{Y}$	● ΔY: Yield difference between new and old technology (kg/ha) ● Y: Average yield, i.e. total production divided by total acreage (ha) ● t: Adoption rate, i.e. acreage under new technology divided by total acreage
2. Computing c	Adoption costs of the new technology, as a proportion of the product price	$c = \frac{\Delta C \times t}{Y \times P}$	● ΔC: Input cost difference between new and old technology ($/ha) ● P: Average product paid to producers in real terms ($/kg)
3. Computing k	Net change in production costs, as a proportion of the product price	$k = [\frac{j}{\varepsilon}] - c$	● ε: Elasticity of supply, drawn from economists' estimates

STEPS	DEFINITION	FORMULA	DATA & TYPICAL UNITS
4. Computing ΔQ	Change in the equilibrium quantity produced due to the new technology	$\Delta Q = \frac{[Q \times \varepsilon \times e \times k]}{[\varepsilon + e]}$	● Q: Total production (kg). Note that Q and ΔQ have the same units. ● *e*: Elasticity of demand, drawn from economists' estimates
5. Computing social gains	Economic benefits from the adoption of research results	$SG = [k \times P \times Q] \pm \frac{1}{2}[k \times P \times \Delta Q]$	●All data are explained above ● Subtract the second term when data are observed after adoption (an ex-post study); add it if adoption has not yet occured (ex-ante).
6. Computing net gains	Net economic benefits, after subtracting the costs of research and extension	NG = SG - R - E	● R: Total cost of research ($) ● E: Total cost of extension ($)

In applying these formulas, it is important to recall that the values chosen for the elasticities of supply and demand (ε and *e*) have far less influence on the results than the other parameters. Indeed, it may be useful to simplify the calculations by assuming that e=0 and that ε=1. Such values are plausible, and result in the cancelling out of the ΔQ term in the social gains formula, which reduces to SG=kPQ. It is also important to recall that the formulas presented here are strictly correct only in the case of linear functions with a parallel shift of the supply curve. But they are not very different from the formulas used in other cases. For example, the original Akino-Hayami formula, described in the following box, was derived with a pivotal shift and with constant elasticity curves.

BOX F. THE AKINO-HAYAMI FORMULAS

One of the original studies pioneering the economic surplus method is the famous article by Masakatsu Akino and Yuhiro Hayami entitled "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development" (*American Journal of Agricultural Economics* vol. 57, no. 1, pages 1-10, February 1975). Since Akino and Hayami use somewhat different formulas than this manual, it may be useful to compare the two approaches. Their work specifies constant elasticity curves and a pivotal shift in supply, using the following formulas:

Demand: $Q = H \cdot P^{\varepsilon}$ (In the original, γ is used instead of ε)
Supply with research: $Q = G \cdot P^{-e}$ (In the original, η is used instead of e)
Supply without research: $Q = (1-h) G \cdot P^{-e}$

Along these curves, elasticities do not vary with the level of price and quantity, but the mathematical relationships are clearly more complicated than with linear curves. One difference is the relation between the parameter h (shift of the supply curve) and the increase in production (that we have called j and that Akino-Hayami has called k). In the Akino-Hayami case, the relationship is approximate:

$h \approx (1+\varepsilon) j$
$j = (Y_n - Y_t)/Y_n = 1 - Y_t/Y_n$
Y_n = yield per hectare with the new variety
Y_t = yield per hectare with the traditional variety

Note that the increase in yields is relative to the new variety because the basic data (P,Q) are observed ex-post with the contribution of research .

The Akino-Hayami formula for social gains (SG_{AH}) is:

$$SG_{AH} \approx jPQ + ½PQ[j(1+\varepsilon)]^2/(e+\varepsilon)$$

This formula generally provides lower gains than our method:

$$SG = kPQ + ½PQk^2 e\varepsilon/(e+\varepsilon)$$

The triangles are similar, but the area of jPQ may differ from the rectangle kPQ, since:

$$k = (j/\varepsilon) - c$$

The formula SG_{AH} generally doesn't include adoption costs. It is thus necessary to subtract them separately from social gains, as a separate step in the analysis.

DATA COLLECTION AND USE

The previous section presents the basic formulas and data requirements needed to calculate the economic gains from the adoption of a new technology. We now turn to the equally difficult problem of collecting appropriate data, and using it appropriately. The data needed to calculate social gains fall into three broad categories:

- "Market" data on observed prices and quantities
- "Agronomic" evidence on yields and costs of the technology being adopted, and
- "Economic" parameters on the market response to change.

In addition to these data on social gains, it is also necessary to obtain:

- Research and extension costs incurred in obtaining the new technology.

Each category of data comes from quite different sources, and needs to be evaluated and used differently.

Market data on prices and quantities

Perhaps the most fundamental pieces of data required for an impact assessment are the price (P) and quantity (Q) of the product that is affected by technical change. A given technical change (say, a 10 percent cost reduction) has a greater economic value if it occurs for a larger-volume, higher-priced product. Technical change for low-volume, low-priced products can bring the same impact only by providing larger proportional cost reductions, or achieving them with lower research and extension costs.

Data for the price (P) variable are typically available from Ministries of Agriculture, extension services, or statistics services. But often several different kinds of prices are available, and in some cases researchers will have to do their own price surveys. The researcher's goal should be to obtain the marginal price, representing what would be paid for any increases in production which might arise from technical change. Realistically, it is typically most appropriate to use an average of wholesale prices from the country's main rural or peri-urban marketplaces.

To assess impact in terms of economic surplus for the entire economy, prices should reflect opportunity costs for the entire economy. Where market prices do not equal social opportunity costs, because of trade restrictions or other distortions, it is desirable to obtain estimates of those social opportunity costs in place of the market prices. Typically, this involves estimating the export or import price of the item in foreign currency at the country's border, then adding (for imports) or subtracting (for exports) the marketing costs to reach local wholesale markets, and converting domestic into foreign currency at an estimate of the equilibrium rather than the market exchange rate.

When trading is relatively free of monopoly control or government restrictions, market prices tend to be very close to social opportunity costs. But if this is not the case, it is important for researchers to make the effort required to obtain estimates of border prices, marketing costs, and equilibrium exchange rates. Most often this is most appropriately done by consulting with economists outside of the agricultural research system, in local offices of the Ministries of Finance or Planning, the Central Bank, or donor agencies concerned with economic policy.

Data for quantities (Q) are often drawn from the same sources as prices. What is usually wanted is the total quantity produced in the country or region where technical change is occuring. Typically this is done at the national level, because that is the area of greatest interest to policy-makers. It is possible to undertake a given impact assessment at any location or level of the market, as long as all of the data used correspond to that same definition of the area being served.

For ex-post studies that use past prices, it is usually necessary to “deflate” them (i.e. remove the effects of inflation). This is done most easily by dividing the observed price by a consumer price index (CPI), which has been calculated so that the value of the index at a given date (e.g. 1990) is 1. This would transform all of the observed prices into “real” prices, at 1990 values.

For ex-ante studies that project future prices, the usual practice is to assume that real prices will remain equal to some average of recent prices. There is likely to be much fluctuation around that average, but it very difficult to predict the direction or magnitude of any trend.

Agronomic data on yield gains and adoption costs

It is not possible to assess the impact of research without data on the technology it produces. For most cases, these data can be expressed in terms of production increases and adoption costs.

Production increases, which are captured in proportional terms using the parameter “j”, are the combined result of the gains from adoption and the adoption rate. Both variables are critically important for any impact study. For example, imagine a new technology which increases a crop’s average yield by 0.33 metric tonnes per hectare, in an environment where the average yield is 1.5 mt/ha. Thus the proportional gain from adoption is a production increase of 22 percent (.33x1.5). If the adoption rate is 50 percent, then the overall production increase will be 11 percent (.22x.5). Applying the formulas used above, we have:

$$
\begin{aligned}
j &= 0.33\ (\text{t/ha}) \cdot 0.50 / 1.5\ (\text{t/ha}) \\
&= 0.165 / 1.5 \\
&= 0.11
\end{aligned}
$$

Information on yield changes typically come from a combination of field trials and farm surveys. It is extremely important to ensure that the data used are as unbiased as possible. Since yield gains from station and even on-farm trials are typically far larger than the gains actually obtained by farmers, and the yield gains obtained by early adopters are typically larger than those obtained by the average farmer, it is usually necessary to apply a correction factor based on past differences between trial data and actual farm performance.

Information on adoption rates typically come from a combination of farm surveys and extension workers' estimates. Sales of seeds and other inputs may also be helpful. It is rare that any one source of adoption data is sufficient in itself; most often it is necessary to supplement survey or seed-sales data with extrapolations and expert estimates, covering farmers in other areas and in other years. For a some products in some countries, input supplies and product marketing are so tightly controlled that complete data are readily available. This is the case for cotton in Senegal (the case study presented in the text boxes), but for most food crops it is not the case.

Information on adoption costs is often forgotten in impact assessments, but must be included to obtain accurate results. Adoption costs include the value of labor, livestock and capital inputs provided by the farm household, as well as any purchased inputs such as fertilizer, seeds or chemicals required to obtain the yield increases associated with the new technology. Again, these adoption cost are most conveniently expressed in proportional terms relative to the total marginal cost of the product, which is approximately equal to its market price.

Typically, cost data are presented on a per-hectare basis. For example, imagine that the yield gains presented above required an annual investment of 10 000 FCFA/ha, above the costs of the existing techniques. This figure must be divided by the average yield (1.5 mt/ha) to obtain adoption costs on a per-unit basis, multiplied by the adoption rate (50 percent) to obtain overall adoption costs, and then divided by the product price (5 000 FCFA/mt) to obtain the proportional adoption cost. Applying the formulas above, we would calculate:

$$\begin{aligned} c &= (\Delta C \times t) / (Y \times P) \\ &= 10\,000\ (\text{FCFA/ha}) \times 0.50 / [1.5\ (\text{t/ha}) \times 50\,000\ (\text{FCFA/t})] \\ &= 5\,000\ (\text{FCFA/t}) / 75\,000\ (\text{FCFA/t}) \\ &= 0.07 \end{aligned}$$

In this case we estimate a production cost increase of 7 percent, to obtain the production gain of 11 percent calculated above. Clearly this is a profitable technology, but the exact economic value of adoption requires some additional calculations.

Before going forward, it may be important to note that researchers may prefer to compute j and c only for adopters, and then multiply both by the adoption rate at the end of the computations. This avoids having to use the adoption rate (t) in two separate formulas, but adds a separate step to the calculations.

Economic parameters on supply and demand response

In the example given above, a production increase of 11 percent was obtained with a 7 percent increase in input costs. This is not yet the end of the impact assessment, however, because the economic benefits from this achievement depend on its relative value, compared to other ways that production can be increased, and compared to consumers' preferences.

Producers' relative difficulty in increasing production is captured by the supply elasticity parameter (ε), defined as the proportional change in quantity produced induced by a one-percent change in price. If this is a small number then increasing production using existing technology is very difficult, and the technical change is relatively more valuable. Typically, the relevant estimates of supply elasicity range from 0.2 to 1.2; they would be at the low end for crops which have little potential for area expansion, typically because they already take up a large share of the available resources, and at the high end for minor crops which have a lot of expansion potential.

Consumers' relative preference for increased consumption is captured by the demand elasticity (e), defined as the proportional change in quantity consumed induced by a one-percent change in price. This number is usually negative, and we use its absolute value in our formulas. If its absolute value is small, then consumers have little interest in expanding consumption, so the technical change results in relatively little increased quantity produced. Instead, the market price will fall. Typically, the relevant estimates of demand elasticity range from 0.4 to 10; they would be at the low end for food crops in a small market, and at the high end for export crops and import-substitutes whose sales can grow quickly.

Elasticities cannot be observed directly. They depend on the attitudes, outlook, production possibilities and the purchase power of producers. They also depend on the length of run that is permitted for adjustment. Elasticities tend to be very low in the short run, and very high in the long run, as a larger amount of adjustment to the price change takes place. It is possible to make statistical estimates of historical elasticities, but the estimates are highly dependent on the circumstances of the analysis. Considering the unavoidable uncertainty related to elasticities, it is important to perform a sensitivity analysis, but such analyses almost always show that the elasticities have little influence on the profitability of research. It is therefore far more important for researchers to focus on estimating the other variables (price, quantity, production gains, adoption costs and adoption rates). It is even possible to avoid any discussion of elasticities, by assuming that e=0 and ε=1.

To show how elasticities are used, we may continue with the example begun above, taking the case of a major food crop whose supply elasticity can be estimated at around 0.3. In computing the shift parameter “k”, or proportional reduction in production costs attributed to the new technology, the production increase (j) is divided by the elasticity following the formula:

$$\begin{aligned} k &= j/\varepsilon - c \\ &= 0.11/0.3 - 0.07 \\ &= 0.30 \end{aligned}$$

In this case, the combination of an 11 percent production increase and a 7 percent cost increase served to shift the supply curve by 30 percent. Where the elasticity of supply is below one, the value of increasing production is magnified by the difficulty of doing so. When it is below one, the value of increased production is dampened. Where the supply elasticity is estimated to be exactly one, then it has no influence (k=j-c).

The final step in estimating the economic gains from adoption is to incorporate the demand elasticity parameter, in determining the change in equilibrium quantity (ΔQ) caused by adoption. In the case of a major food crop, we may estimate the demand elasticity to be relatively low (0.4). This would be applied in the following formula:

$$\begin{aligned} \Delta Q &= Qe\varepsilon k/(e+\varepsilon) \\ &= (Q\times0.3\times0.4\times0.3)/(0.3+0.4) \\ &\approx Q\times0.05 \end{aligned}$$

In this case, the increase in equilibrium quantity from adoption is approximately 5 percent of the observed quantity (Q). This is a relatively small number, because the demand elasticity is small. But consumer prices have fallen, so the research could have a very large economic value. This example illustrates the subtle interactions between various types of data, and their relative importance. Actual social-gain results from the Senegal case study are presented in the box below.

BOX 3. ESTIMATING SOCIAL GAINS IN SENEGAL

In the previous box, we estimated the parameters needed to calculate the social gains from adoption of the new cotton technologies. Now we can put those parameters together, using the formula:

$$SG = kPQ - \tfrac{1}{2}kP\Delta Q$$

In other words, the social gain (SG) in each year will be equal to the product of the k parameter (from table 2.10), the producer price (P, from table 2.8) and the quantity poduced (Q, from table 2.1) minus one half of the product of k, P and the change in equilibrium quantity (ΔQ, from table 2.11). Note that the second term has been *subtracted* because this is an ex-post study, examining the impact of technologies which have already been adopted by some producers. We would have to add the two terms if this were an ex-ante study.

Table 3.1. Computing the Social Gains

Year	k	P (FCFA /kg)	Q (kg)	ΔQ (kg)	Social Gain (FCFA)
1985	-0.02792	67.58	46 913 000	-381 530	(88 878 302)
1986	0.12653	91.46	27 942 000	1 029 738	317 392 648
1987	0.21152	95.59	26 871 000	1 655 453	526 592 546
1988	0.54508	97.27	38 816 000	6 162 512	1 894 632 285
1989	0.73565	96.80	38 703 000	8 292 749	2 460 702 454
1990	0.64195	96.61	29 303 000	5 478 981	1 647 476 967
1991	0.75632	98.42	44 723 000	9 851 891	2 962 477 124
1992	0.68215	98.52	50 577 000	10 048 796	3 061 428 332
1993	0.73210	99.20	47 536 000	10 136 290	3 084 212 888

Cost data for research and extension

So far we have looked only at the social gains from farmers' adoption of research results. But research itself is costly, and extension programs are often needed to accelerate adoption. Thus it is important to subtract the costs of research and extension from the social gains, to obtain net social benefits.

Choosing the appropriate cost data is often among the most difficult tasks of an impact assessment. The first question is to define the start date and scope of the research project being assessed. One cannot assess the impact of all research at once: we must specify exactly which research activity is in question. All expenditure *before* that activity, or any expenditure which *would have been made anyway*, are considered "sunk costs": they would have been spent even if the research did not occur, and so are not part of the research project being evaluated. For example, extension costs which would have been incurred without the research project should be excluded from project costs, even if they helped accelerate adoption.

Research projects being evaluated may be very long in duration and large in scope (say, all of the research since the founding of a particular institute), or very small (say, a recent initiative to produce varieties for a specific area). In either case, social gains should be defined in the same way as project costs: only those technical changes which actually resulted from the specific project should be included. In many situations, some technical change would have occured anyway, and its effects should be included in the "without-project" scenario. This issue may be most important in studies of extension programs, where the without-extension case could include some degree of farmer-to-farmer diffusion.

Once the time period and scope of the project are established, it is still not easy to turn accounting data into appropriate economic costs. Research and extension expenditures are usually not tied to specific technologies, for several reasons including:

- operating costs are shared by several research projects at one time; for example, the plant breeding and agronomy programs often share the same vehicles.
- reseach projects rely on several sources of funding; for example, the national budget or donors.
- NARS often use different accounting systems for each project because of the source of funding. Therefore, a total value which includes operating and investment costs for a given program is difficult to acquire.

- each research project uses results developed by other projects. It is difficult to separate the costs and benefits attributable to a given program.

- research projects extand over several years and accounting systems can change in the meantime, for example, the fuel used by one research program can be accounted as an operating cost for a given program or it can be considered as administrative costs at the level of a research center.

One common practice in estimating research and extension costs is to:

(a) obtain accounting budgets for the whole institute (NARS or IARC or other), and

(b) estimate the percent of resources allocated to the project, often on the basis of the number of staff members and the proportion of their time devoted to it.

Note that, as with all prices, it may be important to correct for inflation by dividing observed costs by a price index, defined as being equal to one in some given year, so that the costs are expressed in constant terms at that year’s prices.

BOX 4. RESEARCH AND EXTENSION COSTS IN SENEGAL

ISRA's cotton research program began in 1983, but was able to use a strong base of results from previous programs. The first new variety was released in 1985, after a very brief start-up period.

Research costs are constant during the first three years of the cotton program, then rise in 1987 and are roughly constant there after. Costs continue up to 1993, because these research activities were needed to support the technologies already released into the field. In other cases, research expenditures associated with the project may end well before the end of project benefits, if the researchers move on to other topics.

Extension costs are roughly constant from year to year, and are quite expensive due to the high degree of support provided to each farmer. It is not clear that all of these extension expenditures are actually needed for technology adoption, but including the full budget for cotton extension programs in the impact assessment ensures that costs are not underestimated.

Total costs in real terms are obtained by dividing the costs in nominal terms by the Consumer Price Index (see table 2.8, column 2).

Table 4.1 Research and extension costs in Senegal (FCFA)

Year	Research costs (FCFA)	Extension costs (FCFA)	Total costs (FCFA)	Total costs (real) (in 1993 FCFA)
1983	25, 100,000	50, 000,000	75 ,100,000	92, 453,091
1984	25, 100,000	50, 000,000	75, 100,000	82, 715,580
1985	25, 100,000	114, 758,492	139, 858,492	136, 238,022
1986	37, 500,000	96, 211,190	133, 711,190	122, 744,098
1987	62 ,100,000	63, 108,874	125, 208,874	119, 980,445
1988	60, 600,000	71, 519,428	132, 119,428	128, 856,887
1989	60, 600,000	95, 492,974	156, 092,974	151, 557,969
1990	58, 500,000	59, 891,763	118, 391,763	114, 579,634
1991	58, 500,000	107, 338,581	165, 838,581	163, 377,155
1992	60, 000,000	109, 376,827	169, 376,827	166, 862,886
1993	60, 000,000	110, 882,604	170, 882,604	170, 882,604

Discounting the value of research over time

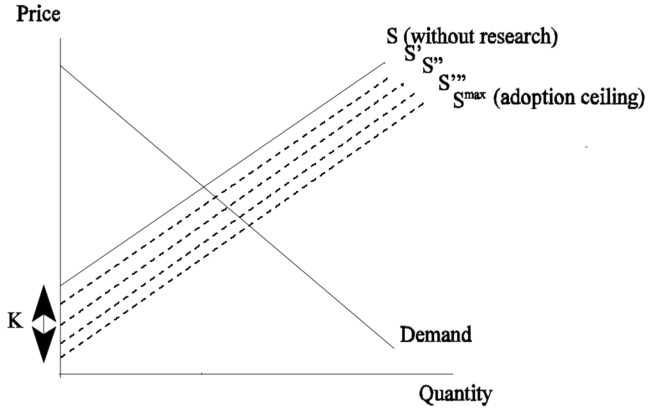
Research benefits and costs are typically spread over many years, and the costs typically some first. To compare values in different years it is necessary to take account of how time affects economic values. Computer spreadsheet software is pre-programmed with the exact formulas used in this “discounting” process, making this step of the calculation very easy.

The most important indicator used to compare discounted costs and benefits is the “internal rate of return” (IRR), or percentage interest rate at which the present value of the costs exactly equals the present value of the benefits. The IRR can be compared to any other interest rate, such as the cost of borrowing funds from a bank, or the returns earned in other investments. If the IRR from the research project exceeds these rates, then the research project was a good investment, in the sense that doing it raised per-capita income relative to what it otherwise would have been.

A second type of indicator that is sometimes used is the project’s net present value (NPV), which is the amount by which total benefits exceed total costs, when these are discounted at some specific interest rate. The interest rate that is chosen should be the opportunity cost of the funds invested, from either additional borrowing or alternative investments. By definition, the NPV computed at the IRR will always be zero.

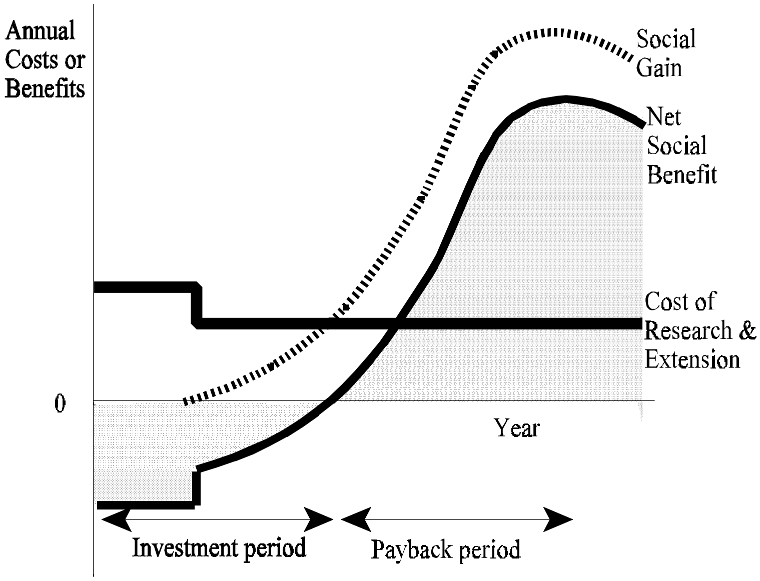
The role of discounting in the impact assessment of research projects is somewhat different than in other project-appraisal contexts. Research benefits are typically more delayed than the benefits of most other projects, and their timing is more uncertain. One reason for this delay is illustrated in Figure 6, showing the progression of the K-parameter over time.

Figure 6. **Supply shifts & K parameters over time**



During the first few years following the development of a new technology, adoption levels may be low, so the supply shift and K-parameter is small. As adoption proceeds, the economic surplus grows exponentially, since it is related to the *area* rather the *height* of the supply shift. Thus, the early benefits from research are often quite low, and it only after adoption is more widespread that the economically most important benefits are achieved. In this case, the supply shift is shown to proceed from S to S' to S", and finally to S^{max} when the adoption ceiling is reached and no additional farmers adopt the technology.

Figure 7. **Social gains, costs, and net benefits over time**



A second reason for the long delay in obtaining gains from research is illustrated in Figure 7: not only do research benefits grow slowly at first, but they do not even start until after many costs have been incurred. The net social benefit, or benefits minus costs, is therefore negative for several years -- often remaining negative even after adoption begins. In the case shown, research costs are highest before the technology is released. At that point, research plus extension costs remain constant at a somewhat lower level, and the social gains begin. But net benefits, or benefits minus costs, do not become positive until adoption is well under way. In the case shown, the gains increase exponentially as the technology is adopted, but soon after the ceiling is reached another technology takes its place and its social benefits are thereby reduced. This typically happens, however, after enough time has passed that its effects on the IRR and NPV are minimal.

BOX 5. THE DISCOUNTED VALUE AND RATE OF RETURN IN SENEGAL

The discounted net present value (NPV) of the research project represents the total economic value of its benefits minus its costs. To compute it, the researcher must specify the interest rate for an alternative investment. To compare across investments, it is most appropriate to use the internal rate of return (IRR), which is equivalent to the interest rate earned on the research investment.

These values are most easily calculated using the pre-programmed formulas in computer spreadsheets. Based on the data calculated in previous boxes and summarized in the table below, the IRR for Senegal's cotton program over the 1983-93 period is 96 percent--far higher than most alternative investments. At an alternative interest rate of 10 percent, the NPV of the research program was FCFA 6 billion, in real (1993) terms.

Table 5.1 Computing the rate of return in Senegal

Year	Social Gains (FCFA)	Research & Exten. Cost (FCFA)	Net Benefits (FCFA)	Internal Rate of Return (IRR)
1983		92,453,091	(92,487,685)	95.74%
1984		82,715,580	(82,709,251)	
1985	(88 878 302)	136,238,022	(225,059,891)	
1986	317 392 648	122,744,098	194,609,186	
1987	526 592 546	119,980,445	406,660,674	
1988	1 894 632 285	128,856,887	1,765,735,282	
1989	2 460 702 454	151,557,969	2,309,155,877	Net Present Value (NPV) at 10 percent (FCFA) 6 284 834 949
1990	1 647 476 967	114,579,634	1,532,867,322	
1991	2 962 477 124	163,377,155	2,799,089,360	
1992	3 061 428 332	166,862,886	2,894,554,611	
1993	3 084 212 888	170,882,604	2,913.330,284	

CONCLUSION: ECONOMIC SURPLUS IN PERSPECTIVE

This manual focuses on the economic-surplus approach to impact assessment. Although it is the most versatile and least data-intensive method, other approaches do exist.

Indicator approaches

One alternative to the economic-surplus method is to ignore economic valuation entirely, and simply use adoption rates, yield levels, quantities produced or other indicators of the perceived success of a particular technology or research program. This approach may be necessary where the other data needed for an economic assessment are missing. But by omitting that information, an "indicator" approach risks producing misleading results.

For example, a new foodgrain technology might be adopted by farmers to help them achieve food self-sufficiency. By increasing yields, it could permit them to meet their goals with less land and labor. But there is often little market demand for surplus food, leading farmers to reallocate those resources to other activities. With the new technology, food production would remain roughly constant, and area planted to the target crop would actually fall. An indicator-based assessment of this technology might conclude that it had failed to make food crop production more attractive. And yet it would have generated a large economic surplus, by releasing resources for use in other activities.

In general, the best single indicator of research success might be the adoption rate, but even this can be misleading. The second computer exercise gives a good example: farmers in Cameroon tend to plant the S-35 variety of sorghum only on small areas, as an "insurance" crop. Thus the old varieties still dominate area planted, and yet S-35 fills an important need and has a high economic value. Other technologies could have similarly "hidden" benefits, as a small amount of adoption yields large economic gains.

Econometric approaches

The economic surplus approach may be criticized for focusing on specific research projects, which may not be representative of other research activities in the system. The projects being assessed may be seen as exceptional failures, or exception succeses. For this reason, many researchers prefer statistical estimates of the average impact of many different research activities over a long period of time. In this situation, econometric research is needed to establish the statistical relationship between outputs and many different kinds of inputs, of which research is one.

An econometric estimate of the impact of research captures the incremental (marginal) effect on production of every dollar spent on research during the study period. Since it is quite difficult to distinguish the impact of research from other factors such as input prices, rainfall, or farmers' education, these studies are typically undertaken only where large amount of data are available. In addition, the estimated impact may be quite sensitive to the specification of the functions used to estimate the impact parameters. Thus, econometric method is usually most appropriate in academic studies, and is not used in contexts where data are limited and results are needed quickly.

Programming methods
An important criticism of all the methods seen so far is that they provide little guidance as to what technologies or research activities would actually be most desirable. In the programming approach, researchers seek to identify the one or more best activities or techniques out of some set of alternatives. This is done by specifying a mathematical model which quantifies the objective and constraints, for example, to maximize something while taking into account something else. Many different types of models are available: the simplest are "linear" programming models, but a variety of other types of models can also be constructed to simulate particular situations. Advances in computer technology have made the use of these models far easier now than in the past, but they remain more complex and generally more data-intensive than the economic surplus approach.

Programming models can represent the choices of a farm, a region or a sector of the economy, or they can represent the choices of a government or research agency. The objective in the case of a research agency might be to maximize the economic surplus impacts from its activities, subject to limitations on its personnel and other resources, and specified probabilities of specified types of research achievements. Such a model would, in effect, be based on ex-ante impact assessments of a range of possible projects, so as to choose what combination of projects is most likely to maximize total economic surplus or meet policy-makers' other objectives.

Programming models are most often used to represent farm-level decisions, so as to show how one or more new technologies is affects farm operations. Such a model would specify the farmers' objectives and constraints, and be run both with and without the availability of the new technology. In its simplest and most common form, farm programming models would specify the objective to be maximizing profits, and the constraints being the availability of land, labor, livestock and other inputs. The model with the new techniques shows how its use changes the use of each factor, and changed production of other goods.

The econometric and programming approaches to impact assessment are essential in some situations, but generally require a very intensive research effort. Each case typically calls for a custom-made model, and specific types of data and analysis. The economic surplus approach, on the other hand, offers a simple framework which can be adapted to a wide range of problems, producing useful results with relatively little data. Through the analysis, examples and computer exercises provided with this manual, researchers with limited previous exposure to economic analysis should be equipped to carry out extremely effective economic impact studies. In this way, scientists from all disciplines can make major contributions to the visibility of their work, and thereby ensure the continuation of high-quality research in future years.

APPENDIX: INSTRUCTIONS FOR COMPUTER EXERCISES

The following section provides detailed instructions for completing the three computer exercises.

In these instructions, the data are presented for each of the three examples exactly as they appear in the spreadsheet files “example1.wk1", “example2.wk1" and “example3.wk1", but completed formulas have already been entered in the shaded cells.

As you work through each of the three exercises on your own computer, your objective should be to replicate the results found in the shaded cells, by reproducing the formulas indicated in the text.