# *Staff Paper*

**Assessing Economic Impacts of Natural Resource Management Using Economic Surplus**

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# ASSESSING ECONOMIC IMPACTS OF NATURAL RESOURCE MANAGEMENT USING ECONOMIC SURPLUS

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# Assessing Economic Impacts of Natural Resource Management Using Economic Surplus


## Abstract

This paper outlines the economic surplus approach to economic impact assessment and how it may be applied to natural resource management (NRM) projects. Three challenges confront NRM impact assessment: measurement, attribution, and valuation of non-market impacts. While various methods for non-market valuation have been developed, none has yet been integrated into a market-based economic surplus analysis due to problems of measurement and theoretical consistency. Future research should address those integration problems as well as the effects on valuation of inter-country income differentials.


## Introduction

Over the past three decades, major advances have been made in the economic assessment of agricultural research impacts. Yet in a recent appraisal of accomplishments in the Consultative Group on International Agricultural Research (CGIAR) international agricultural research centres (IARCs), Pingali notes that little progress has been made in measuring the impacts of research on natural resource management (NRM) (Pingali, 2001). In particular, although attempts have been made to conduct benefit-cost analysis of NRM projects, there have been scarcely any attempts to assess the economic impacts of new NRM practices using the economic surplus approach (Alston *et al.,* 1998).

In the aftermath of the Green Revolution, NRM research has seen a resurgence that is pushing beyond its historic focus on soil fertility and conservation. But assessing the economic impacts of technologies that are not embedded in an improved seed can be difficult. Particular challenges for NRM impact evaluation are attribution, measurement and valuation. First, like other types of cross-commodity research, NRM often defies easy attribution of its impacts. Clearly, yield gains from genetic research are attributable to the research investment. But many NRM research projects modify existing technologies or document benefits of established conservation practices (some of them very old). If soil is conserved because farmers built earthen terraces, is it attributable to public research that refined terracing techniques? Second, measurement of any research impact hinges on documenting the difference in output with and without the new technology. For NRM practices, establishing the counterfactual case (what would have happened without the NRM technology) is tricky because measuring biophysical impacts on natural resources can be costly, imprecise, and slow. How much soil, that would otherwise have eroded, was conserved by the earthen terraces? Would some other field receiving the eroded soil have realized offsetting gains? Third, assigning economic values to these outcomes is fraught with difficulty. Is the value of averting soil erosion on a field simply the value of changed productivity on that field over time? Or does it include costs and benefits on the fields and waterways to which the soil moved? How long is long enough to measure effects that cumulate over time?

The economic surplus framework for impact assessment aims to capture both consumer and producer net benefits from new technologies. New technologies change the total amount of economic surplus as well as its distribution between consumers and producers. In applying the economic surplus approach to NRM impact assessment, estimating the supply shifts due to new NRM technologies and determining how consumers will value those changes requires confronting the triple challenges of attribution, measurement and valuation.

This chapter outlines elements of methods for incorporating NRM indicators into the economic surplus approach to impact assessment. Along the way, it first summarizes the economic surplus approach. Next, it discusses types of NRM research and associated impacts. Alternative methods for placing values on NRM impacts are briefly reviewed, emphasizing cost-effective ways to address measurement and valuation. Finally, the paper surveys and comments upon recent attempts to integrate sustainability indicators into the economic surplus framework, identifying needs for further development of both methods and applications.

## Economic Surplus Approach to Impact Assessment

The economic surplus approach to impact assessment is rooted in the microeconomics of supply and demand. The basic idea is simple and is illustrated in Figure 1. Consumer demand can be described by a downward sloping demand curve illustrating that some consumers are willing to pay more than others for a given commodity, such as sorghum grain. At a market-clearing equilibrium price, p*, those consumers who were willing to pay more than p* realize benefits by getting the product for less money than they were willing to pay. Across all consumers, the area beneath the demand curve, D, and above the equilibrium price, p*, measures the total value of *consumer surplus*. This area measures the aggregate difference between what consumers were willing to pay and what they did pay. Note that some consumers were willing to pay only prices lower than p*, so they did not buy.

Producer supply can be described by an upward sloping curve that illustrates that some producers can supply a product for a lower price than others. At the market-clearing equilibrium price, p*, those producers who could supply the product at a lower price obtain extra benefits. The aggregate benefits described by the area above the supply curve, S, and below the equilibrium price, p*, measure the total *producer surplus*. Together, consumer surplus and producer surplus sum to the *economic surplus*.

The economic impact of a new production technology can be estimated as the change economic surplus that results from a shift in the supply curve. For change in economic surplus to describe economic impact accurately, two assumptions must be met. First, supply and demand curves must accurately depict the values that consumer and producers assign to the product. Second, benefits (surplus) to all actors in the market must be valued equally (Alston, *et al.*, 1998).

New production technologies typically reduce the cost of producing a unit of output. Both yield-enhancing and cost-reducing technologies have the net effect of reducing the average cost of production. The comparative static effects on product supply and economic surplus are illustrated in Figure 2. The reduction in unit costs means that producers can now afford to supply the same amount of product at a lower price (or more of the product at the same price). The new, lower-cost supply curve, S', shifts down (for cost reducing technological change) and/or to the right (for productivity increasing technological change), resulting in a new equilibrium price, p'. All consumers are better off, because the price is lower. Consumers who were buying the product before can now buy it for less, and some new consumers enter the market at the lower price, so that the quantity sold rises from Q* to Q'. Consumer surplus increases by the sum of areas **a** + **c**. The effect on producers is mixed. Producers receive a lower price for their product, so their producer surplus decreases by area **a**. But they are selling more at a lower cost of production, so producer surplus increases by area **b**.

How the effects of a new technology are divided between producers and consumers depends upon the slopes of the supply and demand curves in the neighbourhood of equilibrium prices. The price elasticity of consumer demand is especially important. If consumers are willing to buy any quantity at a given price (the case of perfectly elastic demand where the demand curve is a horizontal line), then cost-reducing technological change creates no consumer surplus and all benefits go to the producers. By contrast, if consumer demand is very inelastic (nearly vertical demand curve), then technological change may lead to a large transfer of surplus from producers to consumers (meaning that areas **a** and **c** are large, potentially larger than area **b**, which depends on the new technology's supply effect alone).

For the class of technologies that reduce the unit production costs of agricultural commodities, the economic surplus approach to evaluating the impact of research and development has been thoroughly described by Alston *et al.* (1998). Indeed, those authors even offer a graphical analysis of how an environmental externality could be incorporated into the economic surplus model (pp. 294-296), assuming that it could be properly measured. However, most NRM technologies present special complications when it comes to measuring the quantity and value of environmental impact for which they are responsible.

**Attribution and Measurement of NRM Research Impacts**

As practiced in crop research institutions, NRM research chiefly focuses on those natural resources that are most closely tied to crop production: soil, water, crop genetics, biodiversity of crop-pest complexes, and human health. A natural resource can usefully be conceived as a stock of natural capital that yields service flows over time that can be enhanced with supplemental investments (Pearce and Atkinson, 1995). Soil quality can be thought of as stock of soil fertility that will deteriorate if drawn down by crop production without fertility renewal. Soil quantity can likewise erode if soil loss occurs at a faster rate than replacement. Water quantity can diminish if used at rates exceeding recharge. Water quality can also diminish of the rate of contamination exceeds the rate of decontamination. Crop genetic resources are a stock that is valued both for current use values and for the option value of potential future productivity gains that they might yield (Evenson *et al.*, 1998). The biodiversity resources of pest-crop complexes include resources in a more abstract sense that includes the ways that species relate to one another, such as the genetic susceptibility of a pest to a given pest control mechanism. Finally, human health is obviously a resource that is fundamental to any system that humans manage. Yet nutrition and exposure to health risks in the production process may render human health another resource whose productivity is endogenous to the NRM system.

The attribution, measurement, and valuation of NRM technologies pose challenges in both time and space. All are complicated by the dynamics of how natural resource stocks evolve over time. Many NRM technologies also have effects that cut across multiple commodities. For example, reduced soil erosion and better water retention due to soil ridging technologies affect all crops on which they are used. But effects vary by geographical setting and the magnitude of an effect often changes over time.

Attribution of identified effects can be accomplished with controlled experiments or simulation models over time. Both can be used to identify and measure changes in crop productivity from soil conservation practices, for example. Gebremedhin *et al.* (1999) used randomly placed experimental plots on Ethiopian farm fields to monitor crop productivity effects from soil movement due to stone terraces of different ages. The experimental design permitted both attribution and measurement of crop yield responses to plot distance from the nearest terrace (Gebremedhin *et al.*, 1999). It also established that crop yields were declining in the absence of terraces. Measurement of such a counterfactual for conservation investments is crucial to establishing the value of NRM impacts that may prevent productivity deterioration, rather than directly increase productivity.

Simulation models provide an apt environment for comparing scenarios 'with' *vs* 'without' NRM technology over time. Simulation models can shorten the time it takes to observe slowly evolving NRM effects on resource stocks and related productivity outcomes. Likewise, they can permit a quasi-experimental setting that may be costly or difficult to maintain in the real world. Crop growth simulation models have been developed that are specifically designed to model changes in productivity in response to several types of NRM technologies, including soil erosion (Pierce, 1991; Sharpley and Williams, 1990; Williams *et al.*, 1989; Yoder and Lown, 1995), soil nutrient availability

(Hanks and Ritchie, 1991; Shaffer *et al.*, 1991), and soil water availability (Hill, 1991; Skaggs *et al.*, 1986).

What to measure and how to do it are related challenges. For on-site productivity effects, controlled experiments and simulation models are very suitable. The consequences of such effects are felt chiefly on-site by the farm household. However, NRM technologies have two other kinds of effects. Some on-site effects are delayed, and may not be recognized at first by the manager. Examples are chronic effects of pesticide use that may not have been properly accounted in the farmer's decision making (Crissman *et al.*, 1998; Rola and Pingali, 1993). Other effects are not experienced by the farm household, but rather are experienced off-site as 'externalities' to the farmer's privately optimal management choices. For example, in some settings, soil erosion may reduce water quality or lead to sedimentation of waterways (Barbier, 1998). By the same token, NRM and yield-enhancing agricultural research may create positive externalities in the form of land-saving effects that protect amenities associated with forests and natural uses (Nelson and Maredia, 1999).

NRM technologies may potentially affect a wide variety of environmental and natural resource (ENR) services, so what to measure depends upon the NRM technology in question and the environmental setting where it is used. What to measure is linked also to those NRM impacts likely to have the greatest social value.

**Valuation of Private *vs* Public NRM Benefits**

As noted above, the benefits of NRM practices can broadly be divided between those captured privately (by the NRM practitioner) and those external to the NRM practitioner that are captured publicly. Table 1 identifies illustrative cases of three NRM practices. Privately captured benefits are the easiest to measure, especially when they are tied to marketed products. If the counterfactual scenario can be established to estimate the change in productivity with and without the NRM innovation, then the annual value of the innovation to adopters equals the net increase in income over the counterfactual alternative. The simplest case would be a NRM practice such as soil fertility management whose effects are wholly captured on-site (i.e., in a locale where off-site effects are negligible). This private value of soil fertility management is the value of yield loss averted plus the costs of any fertilizers that might have been applied to stem yield losses.

Within the realm of private benefits, the next level of benefit covers effects that are still privately experienced but hidden, due to lags or lack of obvious market valuation. Reduction in pesticide-related human health effects is a case in point (Crissman *et al.*, 1998; Maumbe and Swinton, 2003; Rola and Pingali, 1993). If the health damage from pesticide misuse were wholly limited to applicator effects, then all benefits would be privately realized from NRM practices that reduced applicator risk (e.g. pest-tolerant crop variety, safer pesticide, integrated pest management [IPM] practices that reduce pesticide use). However, these health benefits might be delayed, because they involve averting not just acute but also chronic health problems that are slow to develop.

Some NRM practices have public effects felt beyond the NRM practitioner. Such economic externalities are common among ENR services. In particular, production processes for marketed commodities sometimes generate by-products that are bad for the environment. Yet harmful by-products that have no market (e.g. nitrate or pesticide leaching) are prone to be ignored in the producer's benefit-cost calculus. Hence, the value of an NRM innovation that reduces the externality problem may need to be calculated indirectly.

Consider a hypothetical case where the conventional crop production practice requires a toxic pesticide that leaches into drinking water supplies. The dangers posed by pesticide leaching into drinking water represent an economic externality that is ignored by sorghum growers in deciding on input use, but it imposes social costs for pesticide poisoning and treatment. Figure 3 illustrates economy-wide marginal benefit and marginal cost curves that are analogous to demand and supply curves for the crop. The two supply curves differ in that the marginal private cost curve ($MPC=S^p$) represents the private production costs incurred by sorghum growers. By contrast, the marginal social cost curve ($MSC=S^s$) includes the MPC plus the externality cost for pesticide-induced suffering and medical treatment. Because the equilibrium market price, $p^p$, is based on the MPC curve, it results in higher demand for this crop than would result from the actual social costs reflected in the MSC curve (Tietenberg, 1984).

Release of a new crop variety with pest tolerance that does not require the leaching pesticide would generate two kinds of direct social benefits. First, the avoided cost of the pesticide would result in a downward shift of the MPC supply curve with effects similar to those illustrated in Figure 2. Second, substitution of the new variety for the old one would remove the health externality cost that caused the MSC curve to lie above the MPC curve. Removing the health externality cost would create a pure gain in consumer surplus. These two effects result in a double benefit from the new variety due to reduced direct production costs and reduced externality costs. Note that even if growers had to pay as much for the new seed as they had paid for the pesticides, society would still benefit by the reduced externality.[2] The major measurement challenge here lies in estimating the value of the externality, in this instance the value of pesticide-induced illness that could be averted with the new technology.

The thorniest NRM impact valuation challenge occurs when the NR impacts are publicly borne and associated with private use of a public good. A public good is defined as one whose consumption neither excludes nor directly reduces someone else's consumption. The classic problem with public goods is that they tend to be overexploited because individual actors do not face the full costs of their stock decline. Hence, NRM practices that benefit common property resources may not be adopted at socially optimal levels. For example, a productive forage crop may be little adopted because shared natural pastures can be exploited – despite the fact that natural pastures may be losing favoured forage species and diminishing in their carrying capacity. ENR public goods include common property resources, such as pastures, forests, water supplies and the atmosphere. We will not address further the special case of NRM impact valuation on common property resources.

**Economic Valuation of ENR Services**

While markets serve to place values on privately marketed products of NRM research, other methods are required for the economic valuation of human health and ENR services. Three classes of valuation methods dominate: direct market measures, revealed

[2] However, unless the new seed cost was less than the cost of pesticide use, farmers might not choose to adopt the new seed technology. Even when a new technology is available that creates net social benefits, public policy incentives may be necessary in order to induce its adoption (Casey et al., 1999).

preferences inferred from market behaviour, and stated preferences for ENR services that are contingent on hypothetical market settings.

Direct market methods include:

- Cost of remediation
- Cost of illness (including work days lost and medical treatment)
- Cost of alternative production practices.

Revealed preference methods include:

- Hedonic valuation of ENR characteristics embedded in marketed commodities (e.g. real estate value differences due to air quality levels, or wage differentials explained by exposure level to toxic chemicals)
- Averting expenditures made to avoid exposure to some undesired ENR state
- Mitigating expenditures made to reduce emission of some undesired ENR service
- Travel costs incurred to gain access to some desired ENR services.

Stated preference methods are based on survey methods. They include:

- Contingent valuation to estimate willingness to pay (WTP) for ENR services or programs
- Conjoint analysis for ranking ENR alternatives.

There is a large and growing literature on non-market valuation methods for human health (Kenkel, *et al.*, 1994; Viscusi, 1993) and ENR services (Braden and Kolstad, 1991; Freeman III, 1993; Haab and McConnell, 2002). The value of ENR services can be divided between value from direct use (e.g. clean water consumption, avoidance of illness) and from non-use (e.g. the value gained from existence of a resource that could be used in the future or bequeathed to the next generation). Broadly speaking, the direct market and revealed preference methods listed above fail to capture non-use values. Stated preference methods are theoretically the most complete measures of ENR value, but their use has been criticized based on practical difficulties with unbiased implementation (Diamond and Hausman, 1994; Hanemann, 1994).

Evaluating the many alternative non-market ENR valuation methods for use with diverse agricultural NRM technologies goes beyond the scope of this chapter. However, some indicative illustrations are worthwhile. For soil erosion, off-site values associated with sedimentation have been estimated using the cost of restoration approach associated with dredging navigable waterways (Barbier, 1998; Ribaudo and Hellerstein, 1992). For health risk reduction associated with reduced pesticide technologies, the cost of illness approach has been employed (Crissman *et al.*, 1994; Pimentel *et al.*, 1992; Rola and Pingali, 1993). For a broader set of benefits associated with adoption of IPM or avoidance of pesticide risks other than health alone, contingent valuation methods have been employed (Brethour and Weersink, 2001; Mullen *et al.*, 1997; Owens, 1997). Hedonic valuation methods have been used to estimate the value to U.S. farmers of herbicide safety characteristics (Beach and Carlson, 1993) embodied in herbicide price differences and of soil conservation investments embodied in farmland prices (Palmquist and Danielson, 1989).

A key limitation of most health and ENR valuation methods is that they are costly to implement. A small but growing area of research into ‘benefits transfer’ examines the conditions under which environmental values reported in one study may be applied to a different setting. The simplest method of benefit transfer is to take a mean value from a reported study site and apply it to new site. This method has been criticized because differences across sites in both socioeconomic characteristics and biophysical setting may lead to different ENR valuation estimates. An alternative is to transfer a *benefit function*, typically an econometric forecasting equation into which typical values for explanatory variables from the new site may be inserted in order to tailor the predicted ENR benefit values to conditions at the new site. The benefit function approach is generally believed to be more accurate, and was found to be marginally so in a recent controlled study, although both approaches sometimes deviated substantially from on-site surveys (VandenBerg *et al.*, 2001). For economic surplus estimation purposes, the benefit function approach has the important advantage that it can be applied to simulate the variability in benefit valuation across a sample population at a new site, thereby capturing not just the average value of the benefit, but changes along the demand curve of marginal WTP for increasing levels of ENR services.

**Implementing NRM Impact Assessment in the Economic Surplus Framework**

How to accommodate the idiosyncrasies of NRM technology impacts in an economic surplus analysis? Although private and social costs are sometimes combined in theory (as in Figure 3), for empirical work it is more practical to separate privately captured changes in economic surplus due to marketable goods and services from publicly captured externality effects due to non-marketed health and ENR services. Keeping private and public costs separate implies a parallel measurement and valuation process, such as the one illustrated for IPM impact assessment in Figure 4 (Norton, *et al.*, 2000).

Details for conducting an economic surplus analysis of returns to cost-reducing research into marketed agricultural commodities may be found in Alston *et al.* (1998). The key variables for measuring the *ex post* cumulative value of changes in economic surplus for some marketed commodity **j**, as illustrated in Figure 2, are the downward shift in the supply curve (commonly denoted $k_j$ and based upon proportionate changes in output supplied and cost of production), the equilibrium price elasticity of supply ($\varepsilon_j$),, and the price elasticity of demand ($\eta_j$). Estimates of change in economic surplus are typically more sensitive to the estimate of $k_j$ than to the elasticities (Alston *et al.*, 1998).

Among NRM research impacts, the cost-reducing technology approach discussed applies to instances where NRM reduces costs of marketed products. The soil fertility management research in Table 1 is a case in point: The economic impact could be measured by the change in economic surplus, because the benefits accruing from reduced costs and increased yields are entirely captured in a single supply shift, k.

Two other kinds of NRM research impact require different measures of economic surplus. The first is the case of NRM technologies that cause changes in product qualities appreciated by consumers. Such technologies can induce a shift in consumer demand as well as one in producer supply. An example would be pest management that reduces pesticide residue risks to consumers. If consumers wary of pesticide health risks, such a technological change should result in an upward demand shift, with willingness to pay higher prices. Such a research-induced demand shift requires measurement of the demand shift, as well as the supply shift (k). Note that the supply shift need not be negative. Figure 6 illustrates a case where rising production costs shift the supply curve upwards from S to S’, but the accompanying upward shift in consumer demand from D to

D' causes a net gain in producer surplus. Although Figure 6 shows equilibrium quantity unchanged at Q', quantity could increase or decrease, depending on the price elasticities of supply and demand.

The second class of NRM technology requiring a different approach to economic surplus estimation is the case of research affecting economic externalities not faced by the producer. In the special case where the externality incurs a constant social cost per unit produced, illustrated in Figure 3, one can adapt the Alston *et al.* (1998) approach to measure the parallel difference between marginal social cost embodied in the supply curve with and without a new NRM technology. For example, if the external cost of soil erosion were constant per sack of grain produced, such an approach would be valid.

However, the economic externalities associated with NRM technology adoption are typically not constant per unit of marketable product. First, they often exhibit increasing marginal costs, as when increasing output requires shifting production to more marginal settings (e.g. crop farming on more erodible lands). Second, economic externalities typically involve different goods and services than the one being produced for market. Consider the case of soil erosion that causes sediment to deposit in a navigable waterway. Two markets are involved: 1. the market for the crop whose production entails soil erosion, and 2. the market for shipping services on the waterway. A soil conservation technology may cause a cost-reducing shift in supply of the crop. It will also cause a cost-reducing shift in the supply of shipping services. The latter is most accurately estimated directly, despite the common tendency to apply cost of restoration methods (Barbier, 1998). Why not simply apply a fixed cost of restoration per ton of soil eroded? For two reasons: First, restoration is not necessarily feasible or desirable.

Second, the true economic cost is the cost of switching to the next best alternative; that alternative may just as well be shipping by train as dredging the waterway to permit continued barge shipping (Bockstael *et al.*, 2000). Insights into the best alternative and the cost of switching to it are best obtained through direct observation. For cases where economic externalities are important, changes in economic surplus should be measured for a market related to the externality as well as one related to the marketed product. Such measurements typically entail environmental goods and services that are not marketed, so they require inferences either from related indicator commodities for which markets exist or else from constructed markets, as discussed briefly above. Although demand elasticities have been estimated for agriculturally related ENR services (Owens, 1997), none have been incorporated into an economic surplus analysis of NRM impacts, to this author's knowledge.

Those few studies that have estimated the cumulative value of NRM impacts on non-marketed ENR services over time have lacked suitable elasticity estimates and so used a benefit-cost approach. All have assumed constant WTP ('price') for the ENR amenity, implying perfectly elastic demand. Most have likewise assumed that any increased costs associated with producing the ENR amenity were fully covered by privately captured benefits through marketed products, so production costs were excluded from the ENR benefit accounting. The net effect is to estimate the value of a shift in perfectly inelastic supply, like the one illustrated in Figure 5. Ordinarily, this would imply that producers capture all surpluses. However, because the ENR amenity is not marketed, the normal distinction between producer and consumer surplus is meaningless; intuitively, it would seem that consumers chiefly capture the benefits of this shift.

*Translation from consumer WTP units to producer NRM impact units*

Even when monetary values can be estimated for non-marketed ENR benefits from NRM technologies, a secondary challenge is to associate consumer WTP for ENR amenities with producer measures of ENR amenities produced by adopting NRM practices. Two examples serve to illustrate.

Beddow supplemented his estimate of producer surplus associated with the adoption of IPM in sweet corn in Pennsylvania, USA, by estimating the mean value of ENR services gained (Beddow, 2000). He adjusted mean monthly WTP values for reducing eight types of pesticide risks from a contingent valuation survey of consumer households (Mullen, 1995), so that they corresponded with levels of IPM adoption by producers.

A limitation of Beddow's (2000) ENR valuation is that it used unchanging mean values rather than marginal WTP from a downward-sloping demand curve for ENR amenities. Labarta *et al.* (2002) recently drew upon a contingent valuation study that published marginal WTP for improved water quality (Poe and Bishop, 2001) in outlining a method to estimate the ENR value of soil fertility management to reduce groundwater contamination (Labarta *et al.,* 2002). In doing so, they illustrated a method for converting WTP denominated in consumer annual water consumption into values per unit of nitrate leached into drinking water.

A useful extension of the nascent efforts to incorporate NRM innovations into the economic surplus approach would be to apply empirical estimates of supply and demand elasticities for ENR amenities that arise from NRM practices. Supply elasticities would have to be estimated from survey data or multilocational experimental trials that reflect geographic and other differences in producer costs. For example, the marginal cost of pesticide reduction may be less where pest pressure is low. Demand elasticities would likely have to come from survey estimates such as the contingent valuation studies on which the Beddow (2000) and Labarta *et al.* (2002) efforts relied. Compared with the Beddow approach, which was based on average WTP values, the Labarta *et al.* effort uses marginal WTP values that should more accurately reflect consumer values for less-than-total elimination of risk. However, Labarta *et al.* did not build their analysis into an economic surplus model.

Care must be taken in transferring benefits between settings. This is especially true when the settings are very different in biophysical or socioeconomic traits. Useful contingent valuation studies have been conducted of WTP to reduce pesticide-related risks for several crops in the USA, Canada and the Philippines (Brethour and Weersink, 2001; Cuyno, *et al.*, 2001; Higley and Wintersteen, 1992; Mullen *et al.*, 1997; Owens, 1997). However, not only do these apparently similar studies vary in production setting and income level of respondents, some are surveys of consumers, whereas others are surveys of producers. The inferences to be drawn from such different data sources are quite divergent, despite the common focus on valuation of pesticide risk reduction.

*Measuring adoption*

Estimating the discounted cumulative value of NRM impacts over time obviously depends not just upon the value of one individual's adoption, but also on how many adopt. As ably discussed by Alston, Norton and Pardey (Alston, *et al.*, 1998), adoption rates may be projected based on expert opinion about key parameters (e.g. maximum adoption level, beginning date of diffusion, rate of diffusion, likely beginning of disadoption and corresponding rate). More accurate estimates of adoption rates may be had by surveys of adoption (Byerlee and Hesse de Polanco, 1986; Fernandez-Cornejo *et al.*, 2002; Fernandez-Cornejo and Castaldo, 1998; Griliches, 1957). Indeed, expert opinion may deviate substantially from actual adoption levels and may be affected by wishful thinking on the part of experts. A case in point is a 1999 survey of tart cherry growers in Michigan, USA, that found farmers were using no IPM methods on one-third of planted area, whereas IPM experts believed that virtually all farmers were using at least basic IPM practices (Norton *et al.*, 2000).

**Conclusions**

The nascent state of attempts to integrate sustainability indicators linked to NRM technologies into economic surplus analysis leaves ample room for innovation. The area ripest for new contributions is the incorporation of supply and demand elasticities for ENR services so that their valuation becomes more than a benefit-cost analysis exercise. A clear need exists for economic analyses of NRM impacts that incorporate welfare effects from both marketed products and non-marketed products with acknowledged welfare effects.

Additional research into benefits transfer will also be key to clarifying criteria and methods for adapting ENR amenity valuation estimates from one setting to other ones. Until now, most benefit transfer functions and meta analyses have been developed using mostly socio-economic data to capture differences in income influencing the budget constraint that affects consumer willingness to pay. But for agricultural NRM, spatial heterogeneity in the resource base makes integration of spatial biophysical determinants of WTP important as well. Such spatial integration has yet to be attempted.

Moving beyond the scope of the NRM technologies and economic surplus analysis discussed here, there are two areas worth exploring for ENR benefits linked to agricultural research. To the extent that plant-breeding innovations have intensified agricultural productivity per unit of land, they have likely saved land from agricultural use (Nelson and Maredia, 1999). More comprehensive efforts to place value on the ENR amenities so preserved could supplement impact assessments of ENR services due to direct NRM interventions.

The second potentially fruitful effort is to estimate the effect on ENR amenity valuation of rising incomes in developing countries. All the methods reviewed above have presupposed that the value of ENR services is static. However, it has been observed that as incomes rise in developing countries, levels of pollution at first begin to rise; then they decline with rising per-capita income. This bell-shaped relationship has been dubbed the 'environmental Kuznets curve'[3] (Dasgupta *et al.*, 2002; Yandle *et al.*, 2002). It is generally believed to result from two phenomena: a) the replacement of old technologies with cleaner technologies that may also be more productive, and b) rising demand for environmental quality as consumers become wealthier. While most research documenting the environmental Kuznets curve relationship has focused on urban air pollution, the dynamic effects could equally well apply to agriculturally related ENR amenities.

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[3] The curve is named after Simon Kuznets who observed the bell-shaped pattern of correlation between income growth and inequality.

Finally, although NRM technologies can play an important role in reducing health and ENR risks linked to agricultural production processes, policy plays a crucial role for internalizing the externalities that make these technologies worth adopting. Unlike products for which markets function, NRM technologies with increased costs will not be adopted for their ENR benefits alone. If producers perceive no incentive greater than a hypothetical consumer WTP number from a contingent valuation survey, then few will adopt environmentally beneficial technologies. If producers lack incentives to adopt sustainable NRM technologies, then researchers in turn will lack incentives to develop them (Swinton and Casey, 1999). Producer adoption is the *sine qua non* for impacts to occur. So another important role for *ex ante* assessments of NRM impacts is to reveal the value of ENR services that could be had if policy incentives for adoption of sustainable technologies were put in place.

**Table 1.** Common agricultural NRM practices.

| **NRM practice** | **Main private benefits** | **Main public benefits** |
| --- | --- | --- |
| Soil fertility management | Reduced yield decline; reduced fertilizer costs | None |
| Soil conservation | Reduced yield decline; reduced fertilizer costs | Reduced erosion on neighbouring lands; reduced sedimentation of waterways |
| Pest-tolerant crop variety or IPM practice | Reduced pesticide costs; increased crop yields for farmer. Reduced exposure risks to applicator. Reduced residue risk for consumer. | Reduced pesticide risks to drinking water supply and non-target species |

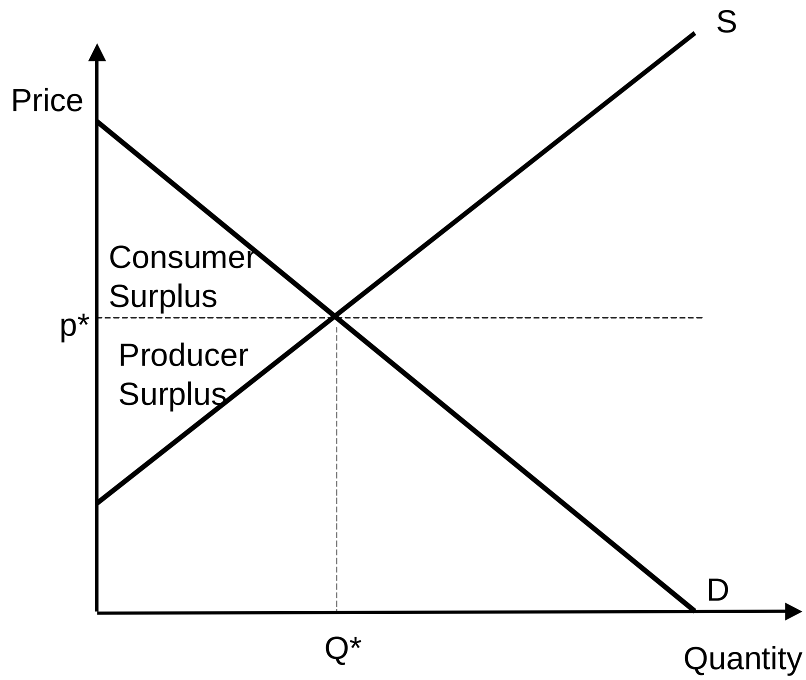


**Figure 1.** Economic surplus divided between consumer and producer surplus.

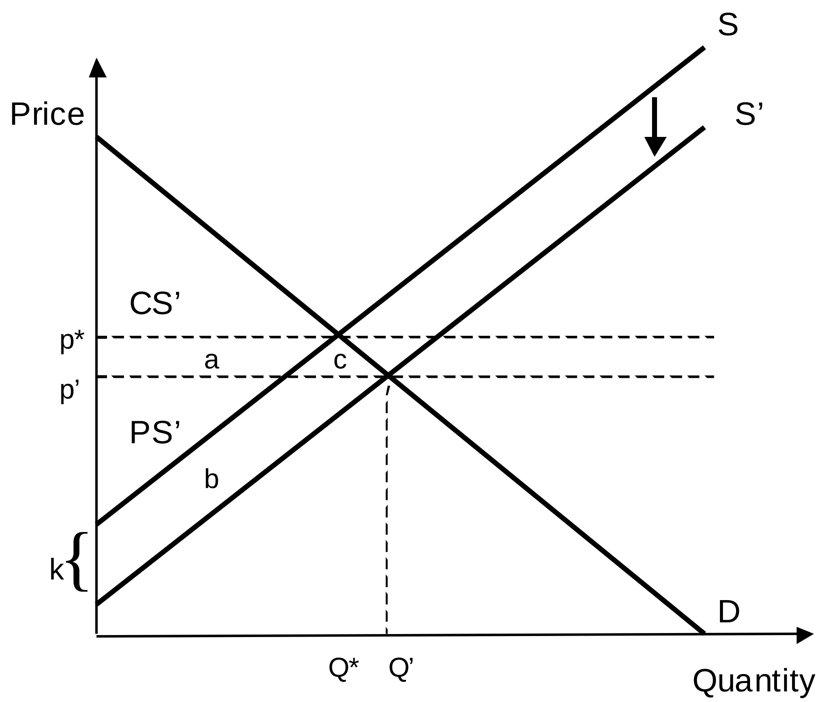


**Figure 2.** Change in economic surplus due to a cost-reducing shift in supply.

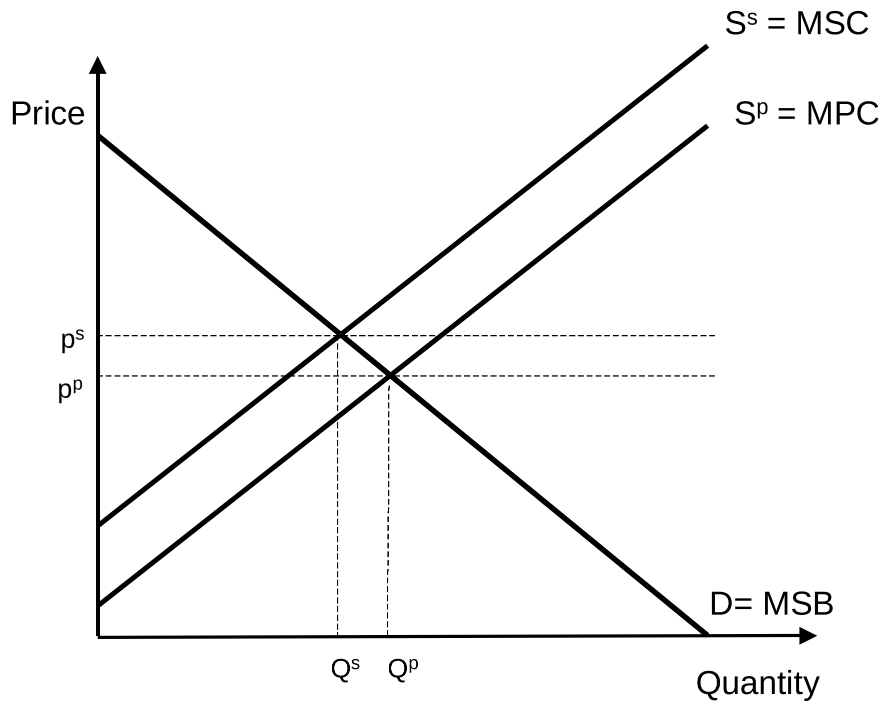


**Figure 3.** Difference between marginal private cost and marginal social cost when production involves a negative environmental externality.

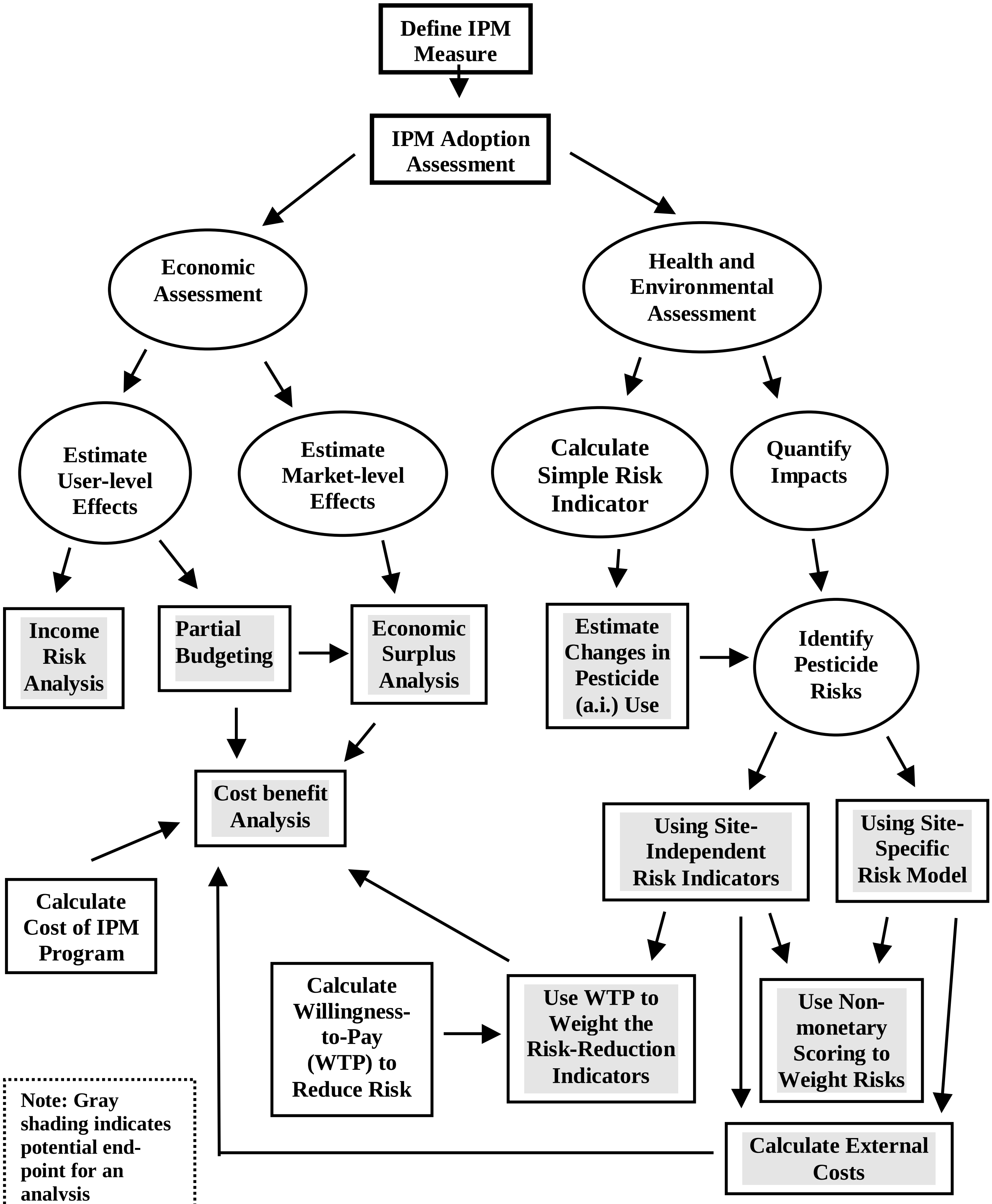


**Figure 4.** Summary chart of the integrated pest management (IPM) impact assessment process  Source: Norton et al. (2000) Figure 4

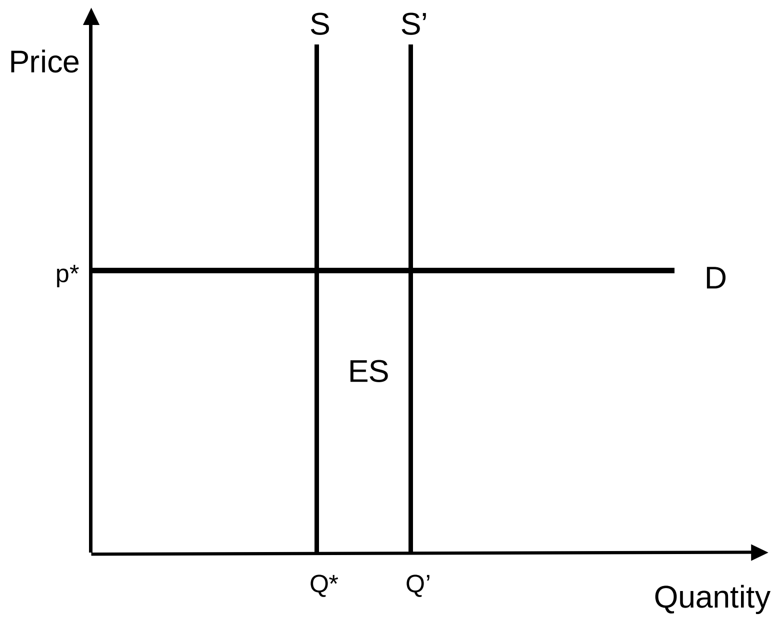


**Figure 5.** Change in economic surplus due to an outward shift in inelastic supply from S to S' when demand is perfectly elastic at price p*.

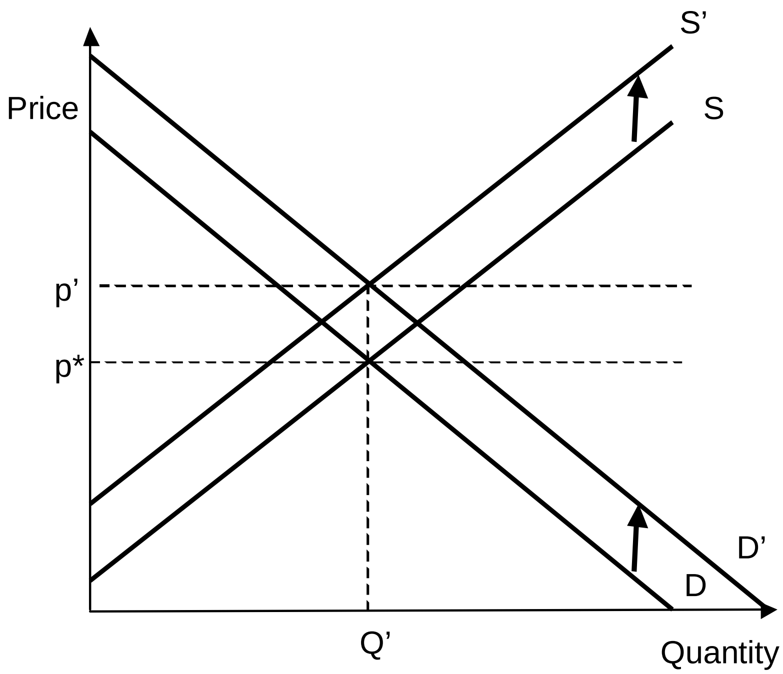


**Figure 6.** Change in economic surplus due to joint upward shifts in supply from S to S’ and demand from D to D’.

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