World Academy of Science, Engineering and Technology
International Journal of Economics and Management Engineering
Vol:7, No:6, 2013

Estimating the Costs of Conservation in Multiple Output Agricultural Setting

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Abstract**—**Scarcity of resources for biodiversity conservation gives rise to the need of strategic investment with priorities given to the cost of conservation. While the literature provides abundant methodological options for biodiversity conservation; estimating true cost of conservation remains abstract and simplistic, without recognising dynamic nature of the cost. Some recent works demonstrate the prominence of economic theory to inform biodiversity decisions, particularly on the costs and benefits of biodiversity however, the integration of the concept of true cost into biodiversity actions and planning are very slow to come by, and specially on a farm level.

Conservation planning studies often use area as a proxy for costs neglecting different land values as well as protected areas. These literature consider only heterogeneous benefits while land costs are considered homogenous. Analysis with the assumption of cost homogeneity results in biased estimation; since not only it doesn't address the true total cost of biodiversity actions and plans, but also it fails to screen out lands that are more (or less) expensive and/or difficult (or more suitable) for biodiversity conservation purposes, hindering validity and comparability of the results. Economies of scope" is one of the other most neglected aspects in conservation literature. The concept of economies of scope introduces the existence of cost complementarities within a multiple output production system and it suggests a lower cost during the concurrent production of multiple outputs by a given farm. If there are, indeed, economies of scope then simplistic representation of costs will tend to overestimate the true cost of conservation leading to suboptimal outcomes. The aim of this paper, therefore, is to provide first broad review of the various theoretical ways in which economies of scope are likely to occur of how they might occur in conservation. Consequently, the paper addresses gaps that have to be filled in future analysis.

Keywords**—**Cost, biodiversity conservation, Multi-output production systems, Empirical techniques.

I. INTRODUCTION

FOR many decades, researchers from a wide variety of different backgrounds have sought to determine the 'best' way in which to protect biodiversity. But contributions from disparate bodies of literature have not always been well integrated. For example, biophysical scientists have historically sought to identify regions where conservation is likely to yield most benefit – but they have not always worked alongside economists, who would, no doubt, have urged them to also consider the costs of that conservation. Nowadays, there is widespread recognition of the need to integrate economics and biology in the conservation sciences [1]-[6], and papers that consider both the costs and the benefits of conservation are becoming more common.

There is a growing body of literature that affirms the significance of "on-farm conservation" as a promising conservation tool [7]-[9]. Other factors that makes on-farm *conservation* programs particularly more *attractive* include impediments such as shrinking conservation budgets, rising land acquisition costs [10], shielding protected areas from a probable novel disturbances introduced by nearby land uses [11], and the higher cost of managing small protected areas relative to larger reserves [12], [13]. Indeed, [14] notes that much biodiversity is on privately owned land – particularly in the UK, Finland, Poland, the US and Australia. As such, it is vitally important to learn more about the costs of on-farm conservation. It is on that issue which this paper focuses – primarily because it is an important, yet under-researched topic.

Some of the early attempts to incorporate costs into conservation planning exercises were, arguably, overly simplistic – assuming, for example, that conservation costs were constant and approximately equal to the 'average' land price, per hectare [15]-[17]. Indeed [18] note that 31 of the 32 articles reviewed by [19] assumed that all sites had the same costs per unit area. Of late, however, there have been many other papers looking at the way in which conservation costs vary across sites in response to a variety of different factors (on occasion, interactively and/or endogenously) such as:

- Conservation action undertaken, e.g.
  - dominant habitat class being conserved [13];
  - irreplaceability and species richness [20] ;
  - size of area conserved/protected [10], [21]-[25], [13], [7];
  - shape of area conserved [13]
- Land values/purchase prices /rent [15], [25], [26], [7]
- Land characteristics, e.g.
  - elevation and soil productivity [2]
  - cover [13]
- Producer prices for crop and livestock products as well as gross rent [27]
- Purchasing Power [22], [1]
- Other social, economic and political factors [28] including, those affecting
  - Implementation [13], [29], [30]; and
  - Conservation planning [28]

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    - Transaction/start-up activities associated with the conservation plan [31]-[33]
    - Cost of maintaining biodiversity and appropriate compensations and management cost [10]
    - Management cost based on area attributes [13]
- Trade-offs between biodiversity and cost
    - Biodiversity planning and cost of foregone [34], [35]

In their review of the literature, [2] categorised the costs considered in conservation studies such as these into five: (1) acquisition of the land; (2) loss of earnings because of a decision to use the land for conservation; (3) management of the conservation program; (4) negotiation, monitoring and enforcement of the conservation program (transaction costs); and (5) potential negative side-effects of the conservation effort (damage costs). But it is important to note, that not all of these types of costs are relevant to all conservation plans. Acquisition costs, for example, are crucial if evaluating plans to withdraw land from agricultural use incorporating it, instead, into the national (park) estate. But acquisition costs are not relevant for (most) on-farm conservation activities.

That said, being able to ignore acquisition costs, does not make the task of estimating on-farm conservation costs (specifically, the opportunity costs from using part of one's land for conservation) 'easy'. Indeed, it is a non-trivial task since much of the information needed to estimate these costs is 'hidden' – i.e. not directly measurable [6], [14], [36]. These costs are hidden because farms are essentially multi-output enterprises, which use a variety of different inputs (e.g. land, rain, labour and equipment), in a variety of different ways to produce a variety of different outputs – only some of which is exchanged in the market (see Fig. 1). As such, there is no simple, observable relationship between input costs and outputs (such as biodiversity). This is not to say, however, that the task of estimating biodiversity costs is impossible. Using Fig. 1 in a stylised example – one could, for example, find two farms that produce an almost identical set of outputs; the important exception being the level of 'biodiversity' produced. One could then compare the costs of production from the low biodiversity producer with those of the high biodiversity producer to estimate the true (marginal) cost of increasing the production of biodiversity from 'low' to 'high'.

A large body of research in the (sub field of Agricultural Economics, considers enterprises that jointly produce multiple products (e.g. cow hides and beef; grain and fruit). Simplistically, those estimating production costs in this context think in vectors rather than variables (e.g. examining the functional relationship between a vector of outputs, a vector of inputs and other property characteristics). As such, these researchers are not just interested in the way in which costs change in response to changes in the number of inputs used (e.g. the size of a property --- and related phrase: *Economies of Scale*), but they are also interested in the way costs change in response to changes in the number of outputs produced (with the related phrase: *Economies of Scope).*

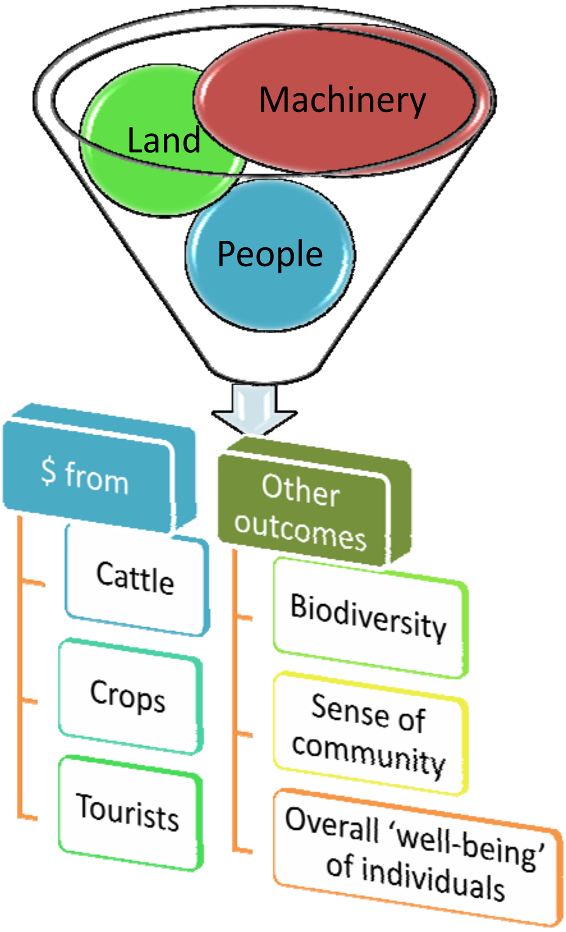

Fig. 1 Stylised representation of a multi-input, multi-output production process

Growing environmental awareness over recent decades has prompted a substantial (related, but not well integrated) literature concerned with the nature of the relationship between agriculture and the production of environmental goods and services, or ecosystem services. Reference [37] attributes the first discussion of this relationship between market and non-market commodities to [38] who rise "the possibility of symbiosis between agriculture and the environment and the possibility of joint production of both [agricultural] and environmental goods and services". Whilst there has subsequently emerged a significant body of literature that examines 'jointness' between agriculture and ecosystem services, predominantly from a biophysical perspective [39], the literature specifically looking at cost synergies between agricultural production systems and biodiversity remains sparse, notable exceptions being [40]-[43] – although [2] uses relevant techniques – namely distance functions – in a slightly different conservation context.

In short, the real-world difficulties confronting those who wish to estimate the 'true' costs of on-farm conservation means that such investigations are rare. This is an important gap in the literature. The potential existence of economies of scope (between agriculture and 'biodiversity') means that then simplistic representations of the cost of biodiversity conservation may overestimate true costs, potentially contributing to suboptimal outcomes.

The purpose of this paper is, therefore, to briefly review literature relevant to multi-output multi-input production functions, paying particular attention to techniques that are potentially useful to those wishing to learn more about the costs of on-farm conservation[1].

II. Multi-Output Production Systems and Conservation Costs

A. Terminology

A number of terms are used within the literature in referring to complementary relationships between elements of a production system, with economies of scope, or scope efficiency being the most prevalent. According to [44] economies of scope are said to exist when the cost of producing two outputs jointly, is less than the cost of producing the same two outputs separately. Reference [45] identify two conditions leading to economies of scope: those which arise when firms are able to save costs by ‘sharing’ variable inputs, and those that arise through the ‘sharing’ of (quasi) fixed inputs[2]. This analysis of economies of scope was extended by [46] and [47] within a multi-input, multi-output context, such that economies of scope are also said to exist when the production of outputs in an integrated manner increases productivity. Reference [46] notes that this extension is particularly relevant when evaluating ecosystem productivity, where at least some inputs (as well as outputs) are not exchanged in the market (e.g. rainfall).

B. Conceptual Approaches

Following [45], economies of scope have been traditionally defined relative to a cost function [48][3]. As such the task of applied researchers is to collect data that allows them to estimate the costs of producing various combinations of outputs. The direct use of cost (and/or profit) functions does, however, have several limitations. Firstly, data on input prices is required and this information is not always observable, particularly where one or more inputs are non-market goods [48] and [49]. Secondly, some inputs have prices that do not reflect their true contribution to the production process [50]. Thirdly, the cost function is of little use when input prices do not differ among firms and so the direct estimation of cost frontier may not be practical and instead an input distance function can be estimated [51]. Finally, the behavioural assumptions that implicit in the [use of] cost functions may be violated in many settings. In this regard several studies [52]-[54] indicate evidence of the violation of underlying assumptions in an agricultural context[4].

It is, however, test for the presence of economies of scope directly from the production technology [50], [51] – providing that one is able to measure production technologies in a way that allows for comparison of firms [50], [47]. Reference [47] developed a general measure of scope economies from the underlying production technology using Luenberger’s shortage function. This method was extended by [50] to analyse economies of scope using a multi-output production function in the context of patents and research and development at US research universities. They argued that the production function approach has several advantages: it is applicable in situations where one or more inputs are non-market goods; it provides a clearer insight into the productivity effects of varying degrees of specialization among outputs; and also allows for a decomposition of scope efficiency into three components: complementarities among outputs (where one output contributes to increased marginal productivity of another); scale effects (reflecting the role of economies of scale) and a convexity component (reflecting

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[1] As such this paper focusses on the opportunity costs of on-farm conservation; issues associated with the equally important and challenging tasks of estimating other conservation costs (such as management, transaction and/or damage costs) remain for other papers.

[2] They define cost complementarities as arising if the marginal cost of production of one output declines with an increase in production of another output(s). With respect to fixed costs, scope economies also arise from the presence of a public input (once purchased to produce one output, the input is costlessly available for the production of one or more other outputs), or from sharing imperfectly divisible quasi-fixed inputs. The authors observe that cost complementarities are a sufficient (but not necessary) condition for scope economies to occur.

[3] In an agricultural context, [81] selected a translog cost function for measuring economies of scope and scale for agricultural supply and marketing cooperatives. The authors cited the advantages of this transformation as placing no restrictions on substitution possibilities among factors of production, while also allowing scale economies to vary with the level of output, such that the cost curve exhibited a classical U-shape. Reference [82] extended the static concept of multi-product scope economies into a dynamic cost-of-adjustment framework and applied it to German dairy farms. Evidence of scope economies were found in both empirical settings. A distinct disadvantage of the standard translog cost function, however, is its inability to accurately model the effects of specialization, leading to biased estimates of economies of scope [83]. Arguing that previous studies employing this method fail to isolate the quasi-fixed cost component of scope economies, [84] estimates a flexible fixed-cost quadratic model to measure scope and scale economies arising within multi-product US cash grain farms, finding strong evidence of both.

[4] Reference [54], employed both deterministic and nonparametric tests to examine the optimizing behaviour of a sample of 289 Kansas farms under profit maximization and cost minimization hypotheses. They found that the deterministic results did not support strict adherence to either hypothesis. Results of stochastic tests showed that all 289 farms failed the profit maximization test, with 171 also failing the cost minimization test. Allowing for non-regressive technical change did not alter the basic results, with 276 farms still violating the profit maximization hypothesis, and 138 farms violating the hypothesis of cost minimization.

Open Science Index, Economics and Management Engineering Vol:7, No:6, 2013 publications.waset.org/13703.pdf

diminishing marginal productivity). The authors note that this breakdown provides for identification of the sources of scope economies at various degrees of specialization.

Reference [40] when estimating supply function of biodiversity, estimates a farmer's marginal private costs of achieving biodiversity objectives at the same time, using trade-off curves relating a given improvement in some biodiversity objectives. The trade-off curves identify how biodiversity objectives can be achieved at lower costs. Interestingly the paper finds that when there is close correlation between land management practices and biodiversity conservation objectives; simultaneous improvement in two conservation targets is no more costly than improvements in the most expensive single target. Or in other words there exists economies of scope (cost complementarity) in protecting biodiversity.

Another way of looking for the presence (or otherwise) of economies of scope is to use distance functions. These offer a number of advantages over standard cost or production function approaches: multiple input and outputs are naturally accommodated [55]; price data, which are often not available or difficult to obtain in a truly exogenous form, are not required [56]; and no specific behavioural objectives are required of the underlying production technology [48]. Developed by [57], [58], a distance function can essentially be thought of as a multiple output production frontier [59], that takes on either an input or an output orientation. An input distance function identifies the minimum input set required to produce a given output vector [55][5], whereas an output distance function looks at the maximum output set (vector) that can be produced with a given input vector[6]. Distance functions can be estimated either parametrically or non-parametrically (see below), and have been used extensively within both the literature measuring scope economies and as well as economic efficiency more generally. Distance functions were first used to measure scope economies by [51][7], but have been used quite extensively within the technical efficiency literature since the mid-1990s (see [49] for early references). They were used by [41] to measure beef cattle efficiency and diversification economies in Australian feedlots. Stochastic input distance functions were used to allow production relations to be expressed in terms of best performance rather than average performance reflecting output complementarities and trade-offs.

C. Empirical Techniques

Early empirical studies of economies of scope in a multi-product setting typically relied on non-frontier estimation techniques [60]-[62] – i.e. techniques that essentially describe a (vector) of outputs as a function of inputs. But as pointed out by researchers such as [63], newer frontier methods (which can be traced back to the seminal theoretical work of [64] and [58] are superior in that they are able to differentiate between high costs that may be due to inefficiencies and those that arise because of scope economies.

Simplistically, frontier methods are used to measure the efficiency of a decision making unit (DMU) by analysing the distance between each DMU's observed level of outputs and inputs and the maximum frontier. A frontier function thus represents a 'best practice' technology, against which the efficiency of firms within an industry can be measured [65]. Production frontiers care empirically constructed either non-parametrically, using data envelopment analysis (DEA), or parametrically, using stochastic frontier analysis (SFA). Introduced by [66] and [67], SFA deconstructs the error term into two components: a non-negative technical inefficiency term and an idiosyncratic error term [68]. In this way SFA distinguishes inefficiency from a random error term, representing noise, measurement error, and exogenous shocks,

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[5] Put another way, it considers the amount by which the input vector may be proportionally contracted while holding the output vector fixed [59], such that the output vector is essentially determined exogenously [72]; [55] therefore view it as:

> "essentially a multi-input, input-requirement function, allowing for deviations from the frontier. It is also conceptually similar to a cost function, if allocative efficiency is assumed, in the sense that it implies minimum input or resource use for production of a given output vector (and thus implicitly costs). However it does so in a primal or technical optimization or efficiency context with no economic optimization implied."

[6] If the production function exhibits constant returns to scale, the input distance function is equal to the inverse of the output distance function [49]. Reference [56] argues that the choice of function is dependent upon whether firms are constrained in their input reduction or in their output expansion. In contrast, [78] argues that choice of orientation should be based on the microeconomic theory of the firm i.e. the objective of the firm is to maximize profits by minimizing costs and maximizing revenues. Minimizing cost involves selecting the optimal levels and mix of inputs in order to produce a given output vector, while revenue maximization involves determining the optimal levels and mix of outputs conditional on the input vector. In this way an input orientation should be adopted in the cost minimization problem, and an output orientation adopted for the revenue maximization problem. In practice however, results from both approaches have been found to be similar [65].

[7] Examining scope economies amongst mixed food and smallholder farming systems in Papua New Guinea, [48] found that the producers under study used very few purchased inputs, with family labour being the predominant input and one that is notoriously difficult to record, particularly in a developing country setting. As an assumption of cost minimization was also unlikely to hold, calculation of scope economies relative to a cost function was not possible. They therefore defined a measure of economies of scope relative to an input distance function, using the second cross-partial derivative of the input distance. The authors note however that this measure is not identical to that obtained using a cost function as it is conditional upon the input mix being held fixed. By contrast, the cost function measure allows the (variable) input mix to adjust so as to achieve minimum cost. They therefore use the term 'diversification economies' rather than scope economies, but view this measure as a lower-bound estimate of the standard cost function measure.

This approach was later extended by [79] who exploited the duality between the shadow cost function and the input distance function to derive a measure of scope economies in terms of the derivatives of the output distance function. Specifically, they showed that the second cross partial derivative of outputs, calculated from the input distance function, is a necessary but is not a sufficient condition for the existence of scope economies. Further, they demonstrated that in the presence of global returns to scale, testing for scope economies from an output distance function is more straightforward. This measure focuses on the sufficient condition of cost complementarities, following [45]. Reference [79] note the advantages of this approach as: the measure is applicable to functional forms which would be otherwise undefined for zero values of output; it avoids the problem of extrapolating the estimated cost function into parts of the data space for which data may be sparse or not available at all, and; the measure can be calculated from the parameters of an estimated distance function.

and therefore does not impose assumptions of allocative and technical efficiency, but allows production to deviate from the efficient frontier [69]. Given the decomposition of the error term, estimation via ordinary least squares (OLS) is not appropriate. The maximum likelihood method is therefore applied to estimate the inefficiency and random error terms simultaneously [68].

DEA was initially introduced by [70] and extended by [71]. It constructs a piece-wise linear production frontier enveloping all observed points [72] and yielding a convex production possibility [73]. Unlike SFA, which uses econometric techniques, DEA is formulated as a linear mathematical programming problem, and is only loosely based on an underlying production technology. The production frontier can be estimated either under constant returns to scale (CRS) [8] or under variable returns to scale (VRS) [73], [72], [55].

Both SFA and DEA measure the inefficiency of a DMU by estimating the distance between the observed DMU and the frontier [74]. A principal difference between the two approaches however is that SFA determines *absolute* economic efficiency, as measured against an imposed benchmark or idealised standard of performance, whilst DEA determines the economic efficiency of a firm *relative* to other firms producing the same good or service [75] [9].

A key advantage of the SFA approach is that it incorporates a random error term. As such, it does not interpret all deviations from the frontier as inefficiency, as occurs under the DEA approach [68], [76]. On this basis Coelli et al. (2005) argue that SFA may be the most appropriate choice in an agricultural setting, where random errors due to weather, disease, and pest infestation are likely to be significant. Even in intensive systems [77] argue that random fluctuations are likely to be important.

A significant weakness of the SFA approach however is that it requires *a priori* specification of the underlying production technology, with the potential for mis-specification of the functional form [77][10]. By contrast, the DEA imposes no *a* priori restrictions on the underlying production technology [52] and [77]; so the researcher need not impose assumptions about the shape and/or location of the frontier [74]. Unlike SFA, it also naturally handles disaggregated inputs and outputs, does not require price or cost data, is computationally convenient and so is highly flexible [52], [74].

Nevertheless, DEA is not a statistical approach and therefore the usual hypothesis testing tools cannot be applied [52]. Moreover, outliers can have a significant impact on DEA results. Because the DEA frontier is constructed from extreme observations, in the presence of “super-efficient” outliers efficiency estimates can behave dramatically and thus be misleading. This is particularly so where the dataset already contains measurement error. Detecting, and dealing with, outliers is thus important when working with DEA[11].

III. CONCLUDING COMMENTS

Scarcity of resources for biodiversity conservation in multiple output agricultural settings gives rise to the need of strategic investment with priorities given to the cost of conservation. Developing a true estimate of cost of biodiversity conservation proves to be a prerequisite in the priority-setting process, and this cannot be done unless practitioners and researchers first acknowledge multi-output nature of on-farm production processes.

The potential existence of economies of scope means that then simplistic representations of the cost of biodiversity conservation may overestimate true costs, potentially contributing to suboptimal outcomes. Consequently, this paper, briefly reviews literature relevant to multi-output multi-

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[8] An assumption of CRS is only valid where all DMU’s are operating at an optimal scale [71]. CRS assumes that all observed DMUs are able to adjust their size and therefore identifies firms departing from optimal scale as inefficient. By contrast, VRS provides for an efficiency comparison corrected for scale influences by comparing only DMUs of a similar scale [72].

[9] Reference [80] was the first to apply DEA to measuring economies of scope. Examining a panel of 468 US banks, the authors defined a measure they refer to as ‘economies of diversification’, a special case of expansion path subadditivity which contains economies of scope as a special case. This measure estimates the cost advantage of output diversification by comparing the required input vector of diversified firms with an estimated additive cost frontier of firms that do not produce some outputs. Reference [85] therefore suggests an approach based on the output expansion resulting from diversification. They show that under constant returns to scale and without economies of scope, the production possibility curve becomes a linear convex combination of specialized firms’ output. As a result scope efficiency is then proportional to the relative distance between the actual frontier and this linear convex combination. This method is also applicable under variable returns to scale if firms’ output is adjusted for the scale efficiency of production. The authors demonstrate that this approach has the advantage of indicating how scale efficiency theoretically modifies the result of scope economies. Specifically they show that under variable returns to scale, the usual definition of scope economies cannot be applied without taking account of the scale efficiency of the DMUs that are compared. One drawback of this method however is that the production of the more specialized DMUs are extrapolated to complete specialization, thereby resulting in an overestimation of scope efficiency that is proportional to the output slack of the most specialized firms. Whilst inconvenient, [85] argues that this bias must be placed in the context of the limitations of other methods, given that no elegant solution exists.

[10] As noted above, behavioural assumptions such as cost minimization or profit maximization may not hold in many agricultural settings. SFA has also been criticized on the basis that it inevitably employs strong assumptions for decomposing the inefficiency and error terms (Newhouse, 1994), and is restricted to a single output or an *a priori* weighted composite of multiple outputs.

[11] This is not a simple task in a multivariate settings (Simar, 2003), although a number of solutions have been suggested. One method, proposed by [86] , uses the proportion of the geometric volume spanned by sub-sets of the data as the basis for calculation. However the geometric method is only applicable in a single output setting. This approach was subsequently adapted to a multi-output setting by [30], but is increasingly computationally prohibitive as the number of observations increases, and does not take into account the frontier aspect of the problem [88]. Based on the concept of the expected minimum input function,[87] proposed a nonparametric estimator that is more robust to extreme values. Arguing that this approach is also cumbersome, [89] offers an approach to detecting outliers that is based on the weight each observation receives during the construction of the DEA hull. They argue that their approach, which is based on dropping observations with the greatest weight, is intuitive and analogous to statistical measures of leverage. It is also easily incorporated into existing DEA programmes, with the weights able to be recovered directly as by-products of the DEA computation.

input production functions, focusing on existing techniques that are potentially useful to those wishing to learn more about the costs of on-farm conservation. Application of these techniques do ***not*** necessarily address all the requirements for estimating "true" cost of biodiversity adequately, so there appears the need to work out how best to adapt most suitable technique.

ACKNOWLEDGMENT

We would like to extend special acknowledgment to Shelley Honeychurch for her valuable contribution early in the project. The team benefited greatly from her excellent research assistance.

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