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Modelling Synergies and Scope Economies between Farm Enterprises and Ecosystem Outputs in the Agricultural Sector in England and Wales

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Abstract

Interest has been growing in the nature of synergies in agroecosystems, prompted in part by growing concerns about the effects of environmental degradation on agricultural productivity and interrelations between agricultural outputs and ecosystem outputs. Most productivity analyses focus on technology, technical inefficiency and scale effects on productivity; yet scope economies derived from synergies can also have substantial effects that are likely to increase in the future. Scope economies take on special importance when farms diversify to halt declining biodiversity and other forms of environmental degradation. We present results of an empirical case study based on panel data on farms in England and Wales. A stochastic input distance function is estimated using Bayesian methods that enable economies of scope to be calculated between pairs of outputs based on the derivatives of the input distance function. Results confirm the presence of scope economies from diversity, providing prima facie evidence that diversity is beneficial in farming systems in England and Wales. But a number of challenges lie ahead to improve the data set and method of measuring scope economies for further substantiation of this evidence. Chief among them is the need to obtain a better measure of ecosystem outputs. The complexity of agroecosystems, with their diverse elements and numerous interactions between elements, presents a major challenge for data collection.

Key words: Biodiversity, ecosystem outputs, scope economies, synergy

Introduction

Increased interest by analysts in the nature of synergies in agroecosystems has been prompted in part by growing concerns about the effects of intensification of farming on biodiversity, and of the impacts of environmental degradation at the farm and landscape levels on agricultural productivity. There is a growing consensus among analysts that a better understanding is needed of the interrelations between the processes producing agricultural outputs and the processes supplying ecosystem services – are there synergies to be exploited, and where, and what are the trade-offs between different farming pursuits and the provision of ecosystem services? One of the main tools available to economists to answer such questions is the measurement of scope economies.

Links between synergies and scope economies

Corning (2002) defined synergy as 'the combined (cooperative) effects that are produced by two or more particles, elements, parts or organisms – effects that are not otherwise attainable'. He listed some of the more important kinds of synergy as functional complementarity, combination of labour, synergy of scale, joint environmental conditioning, information-sharing and joint decision-making, animal-tool symbioses, gestalt effects, cost- and risk-sharing, convergent effects, and augmentation or facilitation effects such as catalysts. Synergies of these types can be found among enterprises and the natural environment in most mixed-enterprise farming systems. Scope economies in farming systems exist when the same level of resource use supports multiple farm enterprises at a lower cost in joint production than in separate production.

A competitive relationship usually exists between elements in agroecosystems, but synergies can reduce the extent of this competition and accentuate the economic advantages of integrating their processes. Measurement of scope economies provides a means to capture the exploitation of synergies that create economic gains. But synergies are not directly comparable to scope economies even though synergy is needed in some form for scope economies to be present. In other words, synergy is a necessary but insufficient condition for scope economies to exist.

Many studies (e.g. Tilman, Wedin and Knops, 1996; Loreau, 1998; Butler, Vickery and Norris, 2007; Yachi and Loreau 2007) signify that it is important to take into account the context in which biodiversity exists. Complementary relationships between species and farming activities are possible, and can be enhanced through synergy. But they are not inevitable and the degree of complementarity may vary spatially, even within the same agroecosystem. It is evident that much scientific research remains to be done if we are to understand better the interactions between biodiversity and agricultural production. Perrings *et al*. (2006:) presented three key research objectives for a better understanding of biodiversity use in agricultural landscapes: '(1) assess biodiversity in agricultural landscapes and the anthropogenic drivers of biodiversity change; (2) identify the goods and services provided by agrobiodiversity at various levels of biological organization (e.g., genes, species, communities, ecosystems, and landscapes); and (3) evaluate the options for the sustainable use of biodiversity in agricultural landscapes'. Their agenda requires new quantitative methods across a number of disciplines, of which economics is one. Our economic analysis is a modest contribution to this agenda. In particular, we use the estimation of scope economies to measure the extent of trade-offs between farm outputs and the production of what McInerney *et al*. (2000) termed countryside assets including specific ecosystem outputs.

Materials and Methods

Analytical method

We conducted an empirical study of the extent of integration between farm enterprises and ecosystem outputs by estimating a stochastic output distance function and measuring scope economies for farms in England and Wales. The estimation of stochastic input and output distance functions is a useful way to test for scope economies using the second cross partial derivatives of outputs. This approach can be applied using data on volumes of inputs and outputs alone. The estimation of stochastic input distance functions has a major shortcoming as a method for testing for scope economies, as pointed out by Hajargasht, Coelli and Rao (2008) who showed that the second cross partial derivative of outputs is a necessary but insufficient condition for scope economies to exist. Testing for scope economies from an estimated stochastic output distance function is more straightforward provided an assumption of global constant returns to scale is satisfied (Hajargasht *et al*. 2008: 3). This estimation method is used in this study.

Farm Business Survey data

Data for the period from 1982 to 2002 are used for model estimation in the study, compiled from the data set compiled in the Farm Business Survey (FBS) for England and Wales. Farm-level data have been collected from farms in England and Wales over a number of decades and recent data are used in this study. This data set was used by Hadley (2006) in his efficiency and productivity analysis of agricultural production in England and Wales. Farm enterprises are aggregated into two categories: crops and livestock. In addition, an ecosystem output variable is included in the estimated model. Inputs are aggregated into 10 categories: fertilisers; seeds; crop protection inputs; miscellaneous crop inputs; livestock feed inputs; livestock health inputs; land rental; management labour; hired labour; and general inputs.

Model formulation

A stochastic output distance function is estimated following Färe and Primont (1995). The stochastic output distance function is specified in translog form as:

$$\begin{aligned} \ln D(x,y) &= \alpha_o + \sum_{i=1}^{M}\beta_i \ln(Y_i) + \sum_{i=1}^{N}\alpha_i \ln(X_i) + 0.5\sum_{i=1}^{M}\sum_{j=1}^{M}\beta_{ij}\ln(Y_i)\ln(Y_j) \\ &+ 0.5\sum_{i=1}^{N}\sum_{j=1}^{N}\alpha_{ij}\ln(X_i)\ln(X_j) + 0.5\sum_{i=1}^{N}\sum_{j=1}^{M}\gamma_{ij}\ln(X_i)\ln(Y_j) \end{aligned} \tag{1}$$

for m output variables and n input variables. The symmetry restrictions imply that $\alpha_{ij} = \alpha_{ji}$ and $\beta_{ij} = \beta_{ji}$. Linear homogeneity with respect to outputs is imposed by normalising one of the outputs. The models were estimated using the FRONTIER 4.1 program (Coelli 1996), which is based on maximum likelihood estimation procedures.

Hajargasht *et al*. (2008) calculated economies of scope between two outputs i and j using the derivatives of the input distance function as the (i,j)-th element of:

$$C_{YY} = C\left\{D_Y D_Y' \quad D_{YY} + D_{YX}\left[D_{XX} + D_X D_X'\right]^{1} D_{XY}\right\}. \tag{2}$$

They pointed out that a necessary and sufficient condition for scope economies for each pair of outputs in the production system is a negative sign on the *i,j*-th element of C_{YY}. They then presented the analogous necessary and sufficient condition for scope economies using the stochastic output distance function as a negative sign for $-D_{YY}(i,j)$ in equation (2), where the $D_{YY}(i,j)$ are second order partial derivatives between output pairs.

Quantifying ecosystem outputs

Ideally, all elements of an agroecosystem should be represented in any analysis of the interrelations between farming activities and the natural environment. But it has so far proved to be impractical to obtain measures, or even estimates, of all ecosystem outputs. As a result, a short-hand measure is needed that captures the essence of the processes involving natural resources to produce a set of outputs, which interact with the processes of farming activities that in turn result in the production of a set of agricultural outputs.

The preferred measure is an agrobiodiversity index of the type devised by Omer, Pascual and Russell (2007) to represent the on-site diversity of species. This index was based on the UK Countryside Surveys undertaken in 1978, 1990 and 1998. The chief obstacle to successful estimation of their model was that the Countryside Survey data are not incorporated into the FBS. The major difficulty in including any such index in a panel data set for conducting an econometric analysis to measure scope economies is matching it to farm-level activities. Recently, more detailed environmental data have been collected in the FBS but they are not yet publicly available for use. Access to these data promises to make the use of an agrobiodiversity index feasible in the future. There is also the matter of determining the appropriate scale at which to apply the index. Should it be measured at the farm or landscape level?

Populations of birds, in general, ‘are considered to be a good indicator of the broad state of wildlife and the countryside because they occupy a wide range of habitats, they tend to be near to or at the top of the food chain and considerable long term data on bird populations has been collected’ (DEFRA, 2009). Butler *et al*. (2007) make a case for using the farmland bird index (FBI) as a proxy for agrobiodiversity on the grounds that agricultural change will affect a bird species if it leads to changes in food abundance and/or nesting success. The FBI is updated annually by DEFRA (2009). Advantages of the FBI data are that they are collected each year and are available in one-kilometre squares, but it was not possible to match the index closely enough to the location of each farm, which can be identified to a 10 sq km grid.

A short-hand method to value ecosystem outputs is to use the environmental payments made to farmers to carry out various preservation measures on their farms. Farmers in the UK are paid to conserve the countryside through the Environmental Stewardship Scheme (ESS) (formerly the Countryside Stewardship Scheme). This information is collected as part of the FBS. A major problem in using data on the ESS payments is that they do not measure the environmental value of farmer actions to conserve the agroecosystem. Fraser (2009) cited a statement by DEFRA (2007, p. 6) that the ESS 'generate(s) financial incentives for farmers to provide public goods they would not otherwise deliver', then makes a compelling case why this is not an accurate measure of public goods. He pointed out that payments made to farmers according to average incomes forgone in a domain of land heterogeneity do not specifically reward farmers for their conservation efforts (see also Harvey, 2003).

Areal, Tiffin and Balcombe (2009) chose the proportion of rough and permanent grassland to total agricultural land area as an ecosystem output variable. They defined permanent pasture as the land used permanently during five years or more for herbaceous forage crops, either cultivated or growing wild. While this variable might be considered a blunt way of capturing the supply of environmental goods, Areal *et al.* (2009) pointed to EC Regulation 1782/2003 to support their use of the variable because of the positive environmental effect of permanent pasture. Its major advantage is that it is readily computed, and for this reason it is the variable we use in this study.

Results

Model results are presented in Table 1 for the input and output elasticities. All input coefficients are of expected sign and significantly greater than zero except for those on the fertilisers, seeds and two labour variables, which are not significantly different from zero. The output coefficients are of expected negative sign and significantly different from zero. The sum of input elasticities indicates decreasing returns to scale exist.

Table 1

Estimates of the input and output elasticities in the stochastic output distance function

Variable	Coefficient	Standard error
Crop outputs	0.087*	0.003
Livestock outputs	0.696*	0.005
Environmental outputs	0.217*	0.005
Fertiliser inputs	-0.003	0.004
Seed inputs	0.001	0.004
Plant protection inputs	0.149*	0.011
Miscellaneous crop inputs	0.198*	0.006
Livestock feed inputs	0.059*	0.006
Livestock health inputs	0.089*	0.005
Land rental	0.208*	0.011
Managerial labour	-0.002	0.005
Hired labour	0.001	0.001
General inputs	0.016*	0.003

* Significant at the 0.01 level of significance.

The measures of scope economies for each output pair are presented in Table 2. The high *t*-values strongly indicate that scope economies exist between all three pairs. The highest measure is between livestock and ecosystem outputs, which is to be expected given the nature of the biodiversity index. The lowest measure is between crop and livestock outputs.

Table 2

Measures of second order partial derivatives between outputs

Output combination	Estimated measure	Standard error	*t*-value
Livestock and crop outputs	0.0071*	0.0021	3.31
Livestock and environmental outputs	0.2672*	0.0033	79.90
Crop and environmental outputs	0.0720*	0.0040	18.03

* Significant at the 0.01 level of significance

Discussion

The results presented above provide *prima facie* evidence that diversity is beneficial in farming systems in England and Wales. But a number of challenges lie ahead to improve the data set and method of measuring scope economies for further substantiation of this evidence. Chief among them is the need to obtain a better measure of ecosystem outputs. The complexity of agroecosystems, with their diverse elements and numerous interactions between elements, presents a major data collection challenge. The challenge does not end with the collection of data because usually there has to be a system put in place to weight the various elements on which data are collected. Weightings may need to be varied across space. The difficulty in weighting different elements in the natural environment suggests that the most practical approach is necessarily a proxy variable, such as the biodiversity index used by Omer *et al*. (2007). In order to circumvent the problems encountered by Omer *et al*. (2007) in obtaining a suitable farm-level index for panel data, the future collection of farm-level data on on-site biodiversity as part of the FBS is a priority.

Chavas (2007) makes a strong case for the use of a shortage function rather than a distance function. Chavas and di Falco (2008) estimated a shortage function to investigate the value of biodiversity in terms of the productive value of services provided by an ecosystem. They proposed a general measure of the value of diversity decomposed into four components: complementarity, scale, convexity (the gestalt effect) and catalytic effects or augmentation effects.

Another dimension of the complexity of agroecosystems is the lagged interactive effects between elements, which can be substantial. It makes the use of cross-sectional data sets undesirable, and even panel data sets require long time series to capture lagged effects to a reasonable extent. Clearly the interaction between the processes producing farm outputs and those producing ecosystem outputs are not constant over time. Farm intensification has lagged effects on the agroecosystem that, in turn, will affect farm production in the long term.

Haines-Young *et al*. (2003) reported different regional patterns of change in land cover, landscape and diversity in UK over the period from 1984 to 1998. Omer *et al*. (2007: 309) observed that ‘biodiversity-related loss of ecosystem services may matter more in biodiversity-poor managed or heavily impacted systems than in biodiversity-rich “wild” or lightly impacted systems’ in UK (see also Perrings *et al*., 2006). In France, INRA (2008) observed different effects on biodiversity according to the intensity of agricultural land use. Incorporating such spatial variations in estimated models to measure differences in scope economies is a challenging task, and one that would require a particularly rich data set. But it is nevertheless important to give a complete picture of the complementarities and trade-offs between different forms of land use in agroecosystems.

The predilection of economists with farm-level studies is understandable in the sense that the richest sets of data are usually to be accessed at the farm level. But analysis at this level has its limitations. It would be useful, in particular, to take a broader, landscape, perspective of ecosystem service management and agricultural production activities. In their summary of studies of agriculture and biodiversity change in France, INRA (2008) emphasised the importance of ‘landscape mosaics’ as a key element for the conservation of biodiversity in agricultural areas. Undertaking economic analyses at the landscape level would be a difficult assignment. Even within the confines of farm-level studies using FBS data, it is not possible precisely to match the FBI to individual farm sites or farm landscapes.

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