The Impact of Dynamic Profit Maximisation on Biodiversity: A Network DEA Application to UK Cereal Farms.

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Abstract

Using a nonparametric framework, we analyse the impact of dynamic profit maximisation on biodiversity for a sample of UK cereal farms for the year 2007. Recognising the drawbacks of directly implementing biodiversity as an output or input in a distance function framework, we only consider inputs and outputs that are clear choice variables from the firm's perspective. We use a dynamic, intertemporal profit function to take into account adjustment costs. We assess how dynamic profit maximisation may shift land use allocation and, as a consequence, the Shannon index for crop diversification. Doing so allows us to calculate the shadow prices of crop diversification in a novel way that is consistent with the dynamic theory of the firm.

Keywords biodiversity, Shannon index, network DEA, dynamic optimisation, shadow value, United Kingdom

JEL code D22, D24, D92, Q15, Q51

1. Introduction

The integration of biodiversity in agriculture is currently high on the European political agenda, as evidenced by considerable changes in the Common Agricultural Policy (CAP) for the period of 2014-2020. Starting in 2015, the CAP's novel "Green Direct Payment" measure links 30 percent of the direct payments to the implementation of land-based biodiversity measures. There are three conditions to receive green payments (DEFRA, 2014): crop diversification, preservation of permanent grassland and maintenance of Ecological Focus Areas (EFAs; *i.e.*, buffer strips, nitrogen-fixing crops, hedges, fallow land, and catch crops and cover crops).

The linkage of payments to biodiversity clarifies that it is essential to assess the trade-off between achieving the biodiversity objective and the economic objective. This trade-off is well-studied in the scientific literature. A common approach is the insertion of a biodiversity proxy as a conventional output in a distance function framework. Typical examples include the ratio of permanent grassland to total agricultural land (Areal *et al.*, 2012), the Shannon index for crop diversification (Sipilainen and Huhtala, 2013), public land conservation (Färe *et al.*, 2001) and wetland conditions (Bostian and Herlihy, 2014).

Treating a biodiversity proxy as an output starts from a public economics perspective. Agriculture does not only provide private goods, but also public, non-marketed goods. Positive externalities that contribute to social welfare should in this regard be priced in order to ensure coincidence of private and public objectives. The distance function approach permits inference of shadow prices for the biodiversity measure by exploiting the dual revenue function.

However, implementing a biodiversity proxy as a conventional output in a distance function framework may be mechanical and theoretically inconsistent. A distance function approach starts from the firm's perspective where firms are assumed to strive for profit-maximising allocation of inputs and outputs. Although society regards biodiversity as an output, farms are concerned with biodiversity to the extent that it increases production and thus consider biodiversity a *means* rather than an end. In other words, farms treat biodiversity as an (indirect) input. On the other hand, implementing biodiversity as a conventional input in a distance function framework would assume that farms strive for minimisation of biodiversity, which would be counterintuitive and undesirable.

These intuitive concerns also lead to a mismatch of axiomatic properties. By treating biodiversity as a conventional output, one implicitly assumes that outputs are produced at the expense of biodiversity, and vice versa. This would imply a monotonically declining relationship between production of outputs and biodiversity, which is unlikely. Crop diversification can indeed be a risk-minimising strategy to avoid production losses. On the other hand, there can be gains from specialisation by exploiting scale economies and increasing technical proficiency, which would coincide with the perspective that biodiversity should be treated as an input (Oude Lansink *et al.*, 2014). Whether the axiomatic properties of biodiversity are more in line of those of inputs or outputs, remains a difficult question to answer *a priori* (Hodge, 2008; Sauer and Wossink, 2013).

Moreover, to the best of our knowledge, all studies that extend the conventional distance function framework with biodiversity proxies assume that farmers are static optimisers and can instantaneously adjust inputs and outputs to their long-term optimal levels. However, adjustments of quasi-fixed factors are in reality coupled with investments (Silva and Stefanou, 2007). This is particularly relevant in a context where farmers incur substantial adjustment costs to reallocate resources in light of environmental objectives.

This paper intends to assess the trade-off between biodiversity and profit in a theoretically consistent way. Recognising the drawbacks of directly implementing biodiversity as an output or input in a distance function framework, we only consider inputs and outputs that are clear choice variables from the firm's perspective. We use a dynamic, intertemporal profit function to take into account adjustment costs. Employing network Data Envelopment Analysis (DEA), we assess how dynamic profit maximisation may shift land use allocation and, as a consequence, crop diversification. Doing so allows for a novel way to calculate shadow prices for crop diversification that is consistent with the dynamic theory of the firm. The application focuses on a sample of 175 English and Welsh cereal farms for the year 2007.

In summary, we contribute to the literature (1) by developing a novel way to calculate the costs of biodiversity gains in a distance function framework while remaining consistent with the firm's objective and (2) by taking into account the adjustment costs.

The remainder of this paper is structured as follows. Section 2 describes our dataset. Section 3 explains the method of our approach. Section 4 presents the results. We conclude this paper in section 5.

2. Data

This study uses data from the Farm Business Survey (FBS) dataset for the year 2007. The FBS dataset provides farm-level information on economic and physical characteristics for a large sample of English and Welsh farms. We distinguish fourteen crop outputs, four variable inputs (seed and planting stock, fertiliser, electricity and heating fuel), two quasi-fixed inputs with corresponding investment (buildings and machinery), and two fixed factors (land and labour). Land is a fixed factor that can be reallocated. Price information is taken from the EUROSTAT (2015) database.

3. Method

Following Ang and Oude Lansink (2015) and Silva *et al.* (2015), firms are faced with a dynamic, intertemporal profit-maximisation problem where they are price takers in a competitive market and have identical, static expectations on the discount and depreciation rates. It is assumed that the firm maximises the discounted flow of profits over time at any base time period, while being restricted by the adjustment-cost technology. In line with Cherchye *et al.* (2015), we make a distinction between joint inputs and output-specific inputs. Joint inputs cannot be allocated to one specific output and are thus needed for the production for multiple outputs. An output-specific input is devoted to one particular output. In our case, we assume that all variable inputs and labour are joint inputs, and that land is an output-specific input. The main advantage of this approach is that it facilitates the detection of inefficient behaviour. The benchmark scenario (A) is solved for each firm $j \in \mathbb{R}_+^J$ by the following DEA problem:

(A) $$rW(p, w, K, c)^{(1)} = \max_{\{y,x,I,\gamma\}} \{p'y - w'x - c'K + W_K(.)'(I - \delta K)\}$$

s.t.

(A.1) $$y_m \leq \sum_{j=1}^{J} \gamma_m^j y_m^j , m = 1, \ldots, M$$

(A.2) $$\sum_{j=1}^{J} \gamma_m^j x^j \leq x_n, m = 1, \ldots, M, n = 1, \ldots, N$$

(A.3) $$\left(I_f - \delta_f K_f\right) \leq \sum_{j=1}^{J} \gamma_m^j \left(I_f^j - \delta_f K_f^j\right), m = 1, \ldots, M,\ f = 1, \ldots, F$$

(A.4) $$\sum_{j=1}^{J} \gamma_m^j G^j \leq G, m = 1, \ldots, M$$

(A.5) $$\sum_{j=1}^{J} \gamma_m^j L_m^j \leq L_m, m = 1, \ldots, M$$

(A.6) $$\sum_{j=1}^{J} \gamma_m^j = 1, m = 1, \ldots, M$$

(A.7) $$\gamma_m^j \geq 0, m = 1, \ldots, M, j = 1, \ldots, J$$

where $W(.)$ is the present value form of dynamic profit maximisation, $W_K(.)$ is the shadow value of capital[1], $y \in \mathbb{R}_+^M$ is the output vector, $x \in \mathbb{R}_+^N$ is the input vector, $K \in \mathbb{R}_+^F$ is the capital vector, $I \in \mathbb{R}_+^F$ is the investment vector, $L_m \in \mathbb{R}_+^M$ is the land vector, $G \in \mathbb{R}_+^1$ is the vector of non-reallocatable fixed factors, $p \in \mathbb{R}_+^M$ is the vector of output prices, $w \in \mathbb{R}_+^N$ is the vector of

[1] $W_K(.)$ is an implicit endogenous variable. However, as all input prices and output prices are known, we find values for $W_K(.)$ by exploiting the dual relationship with the directional distance function (Kuosmanen *et al.*, 2010). The linear program can be solved as a minimax problem where $W_K(.)$ is obtained endogenously.

input prices, $c \in \mathbb{R}_+^F$ is the vector of capital prices, $r \geq 0$ is the rental rate, $\delta \in \mathbb{R}_+^F$ is the depreciation rate, and $\gamma_m^j \in \mathbb{R}_+^M$ are output-specific intensity weights.

DEA problem (B) is similar to (A), but in line with the network model of Färe *et al.* (1997), land use L_m is optimally reallocated among M crops:

(B) $$rW(p,w,K,c)^{(2)} = \max_{\{y,x,I,L_m,\gamma\}} \{p'y - w'x - c'K + W_K(.)'(I - \delta K)\}$$

s.t.

(B.1) $y_m \leq \sum_{j=1}^{J} \gamma_m^j y_m^j, m = 1, \dots, M$

(B.2) $\sum_{j=1}^{J} \gamma_m^j x^j \leq x_n, m = 1, \dots, M, n = 1, \dots, N$

(B.3) $(I_f - \delta_f K_f) \leq \sum_{j=1}^{J} \gamma_m^j (I_f^j - \delta_f K_f^j), m = 1, \dots, M,\ f = 1, \dots, F$

(B.4) $\sum_{j=1}^{J} \gamma_m^j G^j \leq G, m = 1, \dots, M$

(B.5) $\sum_{j=1}^{J} \gamma_m^j L_m^j \leq L_m, m = 1, \dots, M$

(B.6) $L = \sum_{m=1}^{M} L_m, m = 1, \dots, M$

(B.7) $\sum_{j=1}^{J} \gamma_m^j = 1, m = 1, \dots, M$

(B.8) $\gamma_m^j \geq 0, m = 1, \dots, M, j = 1, \dots, J$

Land use is endogenised and is thus an explicit choice variable. Constraint (B.6) ensures that the sum of the optimal land uses is equal to the disposable land area. Note that (A) and (B) are expressions of *variable* dynamic profit. As a result, land use is not included in the objective function, but affects dynamic profit through the intensity weights γ_m^j in the constraints.

The dynamic profit gain from optimally reallocating land use is:

(1) $\Delta rW(.) = rW(.)^{(2)} - rW(.)^{(1)}$ where $\Delta rW(.) \geq 0$

The Shannon index $S(L_m)$ approximates biodiversity by rewarding richness and evenness of crop species. Crucially, it depends on the land use:

(2) $S(L_m) = -\sum_{m=1}^{M}\left[\frac{L_m}{L} * \ln\frac{L_m}{L}\right]$

$S(L_m)$ reaches the maximum when there are M crops that are distributed evenly on the total land area. Analogous to (2), we can define the change in biodiversity due to reallocation of land use:

(3) $\Delta S(L_m) = S(L_m)^{(2)} - S(L_m)^{(1)}$ where $\Delta S(L_m) \lesseqgtr 0$

Finally, we assess the trade-off between dynamic profit and biodiversity by relative comparison of (1) to (3):

(4) $\alpha = -\Delta rW(.)/\Delta S(L_m)$

where α is the shadow price of the Shannon index as it measures the dynamic profit gain/loss of increasing the Shannon index by one unit. A positive (negative) α indicates that more crop diversification decreases (increases) dynamic profit. In contrast to studies that treat biodiversity as a conventional output (*e.g.*, Bostian and Herlihy, 2014; Färe et al., 2001; Sipilainen and Huhtala, 2013), our specification allows for positive and negative shadow prices.

4. Results

Table 1 shows the summary statistics of the calculated shadow prices per hectare. In line with Sipilainen and Huhtala (2013), the shadow price should be interpreted as the dynamic opportunity cost of increasing the Shannon index of crop diversity by 0.1 units per hectare. Although this ranges from -1,500 GBP to 1,894 GBP, most observations do not have such high absolute value. The average shadow price is negative (-15 GBP). This means that growing more crops in a more equally distributed way would be on average beneficial for dynamic profit maximisation.

INSERT TABLE 1

5. Conclusions

Using a nonparametric framework, we analyse the impact of dynamic profit maximisation on biodiversity for a sample of UK cereal farms for the year 2007. Recognising the drawbacks of directly implementing biodiversity as an output or input in a distance function framework, we only consider inputs and outputs that are clear choice variables from the firm's perspective. We use a dynamic, intertemporal profit function to take into account adjustment costs. We assess how dynamic profit maximisation may shift land use allocation and, as a consequence, the Shannon index for crop diversification. Doing so allows us to calculate the shadow prices of crop diversification in a novel way that is consistent with the dynamic theory of the firm.

The results show that the opportunity cost of crop diversification could be both negative and positive. On average, farmers face a negative shadow price. This is an interesting result, as biodiversity proxies are currently treated as conventional outputs in the efficiency literature, which implicitly assumes that there is always a trade-off between conventional production and the delivery of biodiversity and thus a positive shadow price. Our results support the hypothesis that there may be complementarities between biodiversity and production in line with Hodge (2008), and Sauer and Wossink (2013). They also argue against obtaining shadow values by treating biodiversity proxies as conventional outputs in a distance function framework.

Future research will entail (1) a comparison with a conventional treatment of the Shannon index for crop diversification in a distance function framework, (2) a simulation of the novel green CAP measures, and (3) studying multiple years.

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Table 1: Shadow prices of Shannon index for crop diversification expressed in GBP per 0.1 hectares

Minimum	-1,500 GBP
1st Quartile	-113 GBP
Median	- 45 GBP
Mean	- 15 GBP
3rd Quartile	92 GBP
Maximum	1,894 GBP