FACEPA

Farm Accountancy Cost Estimation and Policy Analysis of European Agriculture

The influence of landscape services on farm costs: The case of Swedish milk farmers

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Executive Summary

This study uses information on the economic performance and biodiversity provision of 304 Swedish milk farmers to report research on the relationship between biodiversity and the cost of farming. The biodiversity indicators are based on biological field studies mapping the existence of valuable species in the agricultural landscape while farms' marginal costs are estimated using a flexible cost function.

We find a positive correlation, unconditional as well as conditional, between marginal costs and biodiversity. This relationship is valid when it comes to the binary choice of managing permanent pastures or not, and to providing more biodiversity for those already with valuable pastures. For the main indicator - number of species of vascular plants – a one percentage increase in biodiversity is related to a 0.03 per cent higher marginal cost. If we instead incorporate biodiversity into the farm cost function and assume it to be a variable output, then we also find that an increase of biodiversity boosts marginal costs. Our results therefore support a competitive relationship between the provision of biodiversity and farms' cost structure. This also holds for different types of outputs, but it is more pronounced between biodiversity and beef production.

Weighting the number of species with rarity gives a similar but somewhat weaker relationship, which suggests that the landscape characteristics of pastures with rare species are not more unfavourable for modern agricultural production than other pastures. However, from a biological perspective the landscape properties are of course important for biodiversity, not least the possible networks of habitats. If a pasture is not grazed for a number of years many species will be lost, but with surrounding pastures containing the species a re-colonization is possible. A further examination of the biodiversity at neighbouring farms shows that farms located in areas where neighbours have high biodiversity will on average have higher costs than other farms. The elasticity is similar to that of biodiversity at the own farm, a possible explanation for this being that landscape characteristics influence both biodiversity and the farmers' cost structure.

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Abbreviations and Acronyms

EU	European Union
FACEPA	Farm Accountancy Cost Estimation and Policy Analysis of European Agriculture
FADN	Farm Accountancy Data Network
TUVA	Inventory of biodiversity in Swedish pastures

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Introduction

Swedish environmental policy has 16 specified objectives, one of which is *a rich diversity of plant and animal life*. The long-term objective includes, for example, habitats existing in sufficient numbers to maintain long-term viable species populations, and biodiversity being primarily maintained by a combination of conservation of species and their habitats. More than 40 % of all red listed species in Sweden are present in agricultural landscapes such as pastures and hayfields (Regeringskansliet 2007). Accordingly, the environmental program of *A Varied Agricultural Landscape* has a number of objectives directly related to biodiversity, which implies that agricultural land should be cultivated in order to favour biodiversity, provide habitats and water environments, and preserve endangered species and habitat types.

The reason for such a program is that biodiversity brings value to society, is costly to provide and at the same time the market for biodiversity is non-existing. Hence, the society faces a risk of production below the optimal level. In addition, biodiversity is produced jointly with other farm outputs. Therefore, policy makers do not only have to worry about measuring the potential under-production of biodiversity in order to set up an efficient policy, they also have to consider the nature of how biodiversity is jointly produced with market commodities such as crops, beef and milk (see Wossink and Swinton, 2007). If the production of market commodities and biodiversity is complementary, the possibility of a sufficient provision of biodiversity without intervention arises. However, this isn't the case when market and non-market goods are substitutes or when they compete. Competition between biodiversity and market commodities is found, for example in Peerlings and Polman (2004), but several studies underline that the relationship may be complementary as well (see Romstad *et al.*, 2000; Harvey, 2003; Wossink and Swinton, 2007; Havlik, 2008). This non-linear relationship (i.e. first complementary and then competitive) may lead to difficulties when it comes to setting up an efficient environmental program. The relationship may even differ within small regions, which add to the complexity. Besides, the cost of providing biodiversity is affected by local restraints. For example, Nilsson (2009) argued that the production of biodiversity in regions specialised in animal and milk production may be constrained by the available area of permanent pastures, while farmers in other areas are constrained by the availability of grazing animals.

Still, the Swedish support scheme for pastures doesn't reflect this complexity. The program compensates for higher costs as support comes with a number of technical restrictions, concerning how and when to graze the pasture, in order to prevent permanent pastures from transforming into forest. Although the support may vary with the biological value of the land, the compensation to a particular type of land is a flat national rate. A pasture providing high biological diversity will get 1100 (around 100 euro) SEK per hectare while a pasture with premium values will get even higher support of an additional 2500 SEK (around 230 euro) per hectare (Swedish Board of Agriculture). In order to evaluate whether this program is efficient or not, we need to assess the cost structure of those providing biodiversity through using pastures in their production process. However, to our knowledge, no extensive analysis of the relationship between biodiversity and production costs has been performed on farm level.

The aim of this paper is to fill some of the gaps in the literature by estimating a flexible cost-function for Swedish farms, and to assess the relationship between cost structures and the provision of biodiversity. The incorporation of biodiversity in the cost function is not straightforward, though, and the methodology used in the literature is quite diversified.[1] First, most studies calibrate instead of estimate the relationship between costs and biodiversity, or they focus only on the costs of producing biodiversity without considering a joint cost function. Second, farms entering the environmental program have to fulfil a certain number of specific and long-term commitments. Hence, farmers may not treat biodiversity as a variable output. Third, several local variables, such as climate, landscape, soil quality and neighbouring activity, limit the potential outcome of biodiversity. Finally, the level of biodiversity may not be the strategic variable, since farmers are not paid for the actual provision of biodiversity. Instead, farmers receive a flat rate per hectare in order to manage the pasture according to the preconditions for receiving a payment.

This leads us to use different strategies in order to evaluate the relationship between the supply of market commodities and biodiversity. Our benchmark methodology follows Wieck and Heckelei (2007), which implies that we calculate short-term marginal costs of three different outputs and relate these to farm output of biodiversity. Therefore, we let the distribution of biodiversity reflect the underlying factors determining farm costs in order to evaluate whether there is a relationship between high costs and a high provision of biodiversity. The reason for assuming marginal cost differences among farmers is the restriction (i.e. milk quota) they face when it comes to supplying milk. The second approach is to incorporate the provision of biodiversity in the cost function as an output, which implies that we could investigate the joint cost function in detail. Finally, we investigate the importance of the spatial dimension by including neighbouring farms' provision of biodiversity in both these steps.

The disposition of the paper is as follows. The following section discusses earlier studies on farm output and biodiversity including topics such as joint production, the cost of providing biodiversity and the empirical methodology. The third section contains a description of both the economic and biodiversity data. The fourth section presents and discusses the results, and the fifth section concludes the paper.

[1] See e.g. Romstad *et al.* (2000), Peerlings and Polman (2004), Havlik *et al.* (2005), Nilsson (2007) and Brady *et al.* (2009).

Biodiversity and farm costs

Jointness

The focus of this study is the provision of biodiversity of permanent pastures in Sweden. The supply of such an environmental service is highly dependent on the production choices made on farm level as well as the locality of the pasture. An important reason behind the influence of farm-level choices is jointness in production, i.e. biodiversity is produced jointly with other farm commodities, which stems from three major sources according to *inter alia* Hodge (2008) and OECD (2001). The first source is when the provision of biodiversity is linked to the production of another commodity, such as milk, for example through grazing. Grazing not only feeds the animals but also leads to biodiversity as land is kept open (i.e. there is a technical interdependence). The second source is similar to the first one and arises due to a fixed non-allocable input used in order to produce several outputs. Both beef and biodiversity, for example, are obtained from the use of grassland as a farm input. An implication of such jointness is that the production of beef and biodiversity becomes complementary. The final source is when several "*outputs compete for an allocable input*" (Hodge, 2008), which implies a competitive relationship between outputs.

The complexity of jointness increases in a situation when the relationship between two outputs changes with the level of supply. In the case of biodiversity, the relationship with beef or milk production may be very different depending on the intensity of production, which is discussed *inter alia* by Romstad *et al.* (2000), Havlik *et* al (2005), Wossink and Swinton (2007) and Hodge (2008). First, there is a need for some production or management of pastures in order to keep the landscape open; otherwise the pasture turns into a forest and the biological diversity of the area decreases. This implies that grazing will keep the pasture open and biodiversity will increase with beef or milk production. At some point, however, the grass sward becomes too short as the grazing intensity increases, or when the use of a yield-improving input such as fertilizers is introduced. Thus, the relationship between beef and biodiversity changes and it becomes competitive.[1] In short, the value of a pasture is "*threatened by both overgrazing and undergrazing*" (Hodge, 2008). Nilsson (2009) argued that overgrazing may be less of a problem in Sweden, which suggests a complementary relationship. It is important to notice, however, that this relationship is technical and not economical, which is the focus of this study, and it might be problematic to extrapolate this relationship from pasture level to the cost structure at farm level. That is, a complementary relationship at pasture level may be in line with a competitive relationship at farm level due to other fixed inputs (e.g. livestock or equipment) that have to be allocated between outputs, or to alternative costs of using pastures instead of cultivated grassland. Even if the farmer has a technical possibility of increasing both grazing and biodiversity at the same time, the cost structure at farm level may become worse.

[1] It has also been argued in the biological literature that the diversity–productivity relationships are nonlinear, and that the main causal relationship runs from productivity to diversity due to competitive effects (Grace et al., 2007).

Finally, the provision of biodiversity varies, given the intensity of production, between localities due to biological factors. Hence, we may expect a spatial heterogeneity (Wossink and Swinton, 2007) in the provision of biodiversity. The importance of the locality, or the spatial heterogeneity, is also underscored by Romstad *et al.* (2000) and Brady *et al.* (2009) through the importance of landscape mosaic. The argument goes as follows; the more diverse the landscape, the more valuable it is since the potential for biodiversity increases. However, the relationship may take the shape of an inverted U (Romstad *et* al, 2000). Very high diversity implies very small parcels of land, and each parcel may be less efficient at sustaining a high level of biodiversity. However, a very low degree of landscape mosaic, and hence larger acreage, may also lead to low levels of biodiversity since we have fewer important, for biodiversity, borders between parcels of land. Finally, Romstad *et al.* also underline that the complexity behind the provision of biodiversity may increase by linkages not only with several market commodities, but also with other non-market commodities. The provision of biodiversity may go hand in hand with, for example, cultural heritage, landscape mosaics and rural settlement (Romstad *et al.*, 2000). It may mix badly with recreation and the size of agricultural land, and it may have a complementary or a competing relationship, depending on the amount supplied, with openness and an active landscape (the amount of economic activity).

Is biodiversity costly?

The provision of biodiversity through permanent pastures is related to farm cost in several different ways. The focus of this study is on permanent pastures (or semi-natural pastures), which may be defined as "*old grasslands that ideally have not been exposed to any kind of yield-improving measures such as fertilizers, draining, pesticides, tilling or sowing*" (Nilsson, 2009). As described above, there are two different types of pastures, each facing a different flat rate per hectare in order to keep open, and the focus of this study is on those with the highest value. These highly valuable pastures are also important for animal production since they form around 50 per cent of all grazing land in Sweden (Swedish Board of Agriculture, 2009).

The management of these pastures is costly (see e.g. the discussion in Nilsson, 2009) since the farmer has to put up or maintain fences, ensure access to water and shelter (compulsory according to Swedish law), and move animals between pastures. In addition, the opportunity cost of using permanent pastures, instead of cultivated grassland, is higher, because the yield per hectare is smaller and animal growth lower due to the importance of shady or waterlogged areas in valuable pastures. The Swedish Board of Agriculture (2009) showed, for example, that the yield was lower in pastures with several important biodiversity indicators. Nilsson (2009) also argued that the marginal cost of biodiversity increased with the supply of this environmental service, since pastures further away from the farm or further away from natural water sources would be used marginally. The importance of distance is indicated by the Swedish Board of Agriculture (2009), which showed a large variation when it came to the distance between the farm centre and different pastures. The marginal cost of biodiversity may also increase with the amount provided due to additional fencing, sheltering and transporting.

Earlier studies

The literature on farm output and biodiversity revolves around the two questions above, i.e. the jointness in production and the costs of providing biodiversity. The pioneer work of

Peerlings and Polman (2004), one of few studies using a micro-econometric approach, included the wildlife and landscape services as a quasi-fixed output in a flexible profit function. Using farm-level information on Dutch milk producers, they investigated the joint production of milk and environmental services (measured as the compensation received by farmers), and concluded that these outputs were substitutes.[1] In addition, they showed that most farms have diseconomies of scope, which implies that farms have incentives for specialising.[2]

Most studies, however, calibrate instead of estimate the relationship between different outputs in order to evaluate policy scenarios in a situation with jointness. Havlik (2008) used a short-run cost function with either a complementary or a competing relationship between biodiversity (approximated "*by farmer's compliance with requirements contained in selected agri-environmental agreement*") and beef production. This model was then used to evaluate the impact of decoupling on biodiversity in two regions, which underscored the importance of whether the local relationship is complementary or competitive. Decoupling was found to decrease (increase) biodiversity in areas with a complementary (competitive) relationship. The development of the number of hectares in the Swedish environmental program is in line with a complementary relationship since it fell after 2005 when the 2003-reform of CAP was implemented but other factors behind this trend also seem quite plausible. The Swedish Board of Agriculture (2009) highlighted explanations such as an exclusion of mistaken hectares when the single farm payment was implemented, and a slow impact of a new rural policy initiated in 2007.

Havlik *et al.* (2005) also used a mathematical programming farm-level model in order to investigate how policy instruments affect the provision of grassland biodiversity (measured as hectares of grassland). The results underscored the complexity of setting up an efficient environmental program, as both complementary and competitive relationships were found even in a small French region. Brady *et al.* (2009) used a spatial agent-based model in order to evaluate the impact of the 2003-reform of the EU common agricultural policy on landscape mosaics services and biodiversity (measured as the expected number of species in the landscape, which in turn was approximated by a function of the habitat area and the species' productivity) in several EU regions (two each from Sweden and Italy, and one from the Czech Republic). Three policy scenarios were evaluated, and the results showed, in line with the results above, that decoupling may lead to degradation of biodiversity. Hence, a more efficient environmental program was demanded, which, according to the authors, involves matching local requirements and the use of Pillar II of the common agricultural policy.

Finally, some studies focus on the production costs of biodiversity itself. Nilsson (2009) modelled the cost of biodiversity in two Swedish areas, and then estimated the relationship between the calculated costs and the amount of biodiversity (measured by multiplying pasture area with a biodiversity quality indicator constructed by "*summing...type of land, vascular plant species, bush diversity and maintenance*"). The result showed that costs as

[1] An additional study with a micro-econometric approach but with a slightly different perspective was Bonnieux *et al.* (1998), which investigated the behaviour of farmers entering an environmental program compared to those that declined.

[2] Lack of a complete specialisation in milk in the real world was explained by costs not included in the model (e.g. quota costs) and lack of a complete specialisation in wildlife production may be due to a high risk level when it comes to the production of environmental services.

well as marginal costs of the production of biodiversity increased with the supply of this service, and the cost structure was very different when the two areas were compared, underscoring the importance of locality. An additional Swedish study is Kumm (2004), which compares calculated costs for "*grazing a number of small scattered pastures*...[with]... *an extensive pasture-forest mosaic*". The results show significant differences between these two types of grazing areas, and thus there is a risk of losing the high cost one (i.e. small scattered pastures). Hence grazing should be guaranteed by "*re-creating extensive pasture-forest mosaics*".

Empirical methodology

When it comes to the empirical methodology for the relationship between market and non-market goods, the most common approach is to incorporate a calibrated relationship into a profit or cost optimisation problem in order to evaluate different policy scenarios. Other studies (Nilsson, 2009) sidestep how provision of biodiversity may interact with other variables in the optimisation process by evaluating a cost function focusing completely on the supply of biodiversity. Few studies (the exception is Peerlings and Polman, 2004) incorporate biodiversity in farmers' profit maximisation problem and then estimate the relationship with other outputs, the production technology and the shadow price of biodiversity. In spite of such a variation in the methodology, most studies take their point of departure in jointness. This implies that we may model cost of production as a joint cost function including both the output of the market commodity (e.g. milk) and the non-market commodity (e.g. biodiversity) as in Havlik (2008). That is, the cost function is expressed as:

$$C = c(y_m, y_{nm}, ...), \tag{1}$$

where y_m is the market commodity, y_{nm} the non-market one, and the marginal cost of both these outputs is assumed to be positive. The type of jointness, i.e. complementary or competitive, in production is reflected in how the marginal cost of a market good reacts when the provision of the non-market good increases. If the marginal cost of the market good decreases when the provision of the non-market good increases, we will have a complementary relationship. If there is a positive impact on the marginal cost, we will have a competitive relationship.

The inclusion of biodiversity in a farm's optimisation problem is not straightforward for several reasons. First, farms entering the environmental program have to manage the pasture according to some conditions for a specified period (five years in the case of Sweden), which implies that the farmer, in the short run, has little room for changing the provision (apart from expanding to new areas). Second, the provision of biodiversity is highly dependent on the locality of the pasture and not only on the farmer's choices, due to biological factors as well as to the choices of neighbouring farms. Third, the level of biodiversity may not be the strategic variable, because farmers are not paid for the actual provision of biodiversity. Instead, farmers receive a flat rate per hectare in order to manage the pasture according to the preconditions for receiving a payment.

The complexity of analysing the relationship between market goods and environmental services and the variety of methodology used in the literature have brought about two different approaches for evaluating the relationship implied by equation (1). First, we investigate the distribution of farmers' marginal cost with respect to the provision of biodiversity. This strategy is similar to the one found in Wieck and Heckelei (2007), which implies that we first estimate the short-term marginal cost function and then, in a second stage, relate marginal costs to farm output of biodiversity. The distribution of biodiversity is assumed to reflect the distribution of underlying factors included in the estimation, and thus we may assess whether farms with a high provision of biodiversity are more vulnerable due to higher costs. Weick and Heckelei (2007) investigated the marginal costs among European milk farmers and showed that farmers with a higher share of grassland (an indicator of less favourable location) faced higher marginal costs. Second, we assume (as in Peerlings and Polman, 2004) that the output of environmental services is variable and also a strategic variable used in the cost-minimisation problem of the firm. This means that we incorporate the provision of biodiversity as an output in the cost function, and, by so doing, we may examine in detail whether the relationship between biodiversity and market outputs is complementary or not. In addition to using these two empirical strategies, we investigate the importance of the spatial dimension by including a variable consisting of the average level of biodiversity provision of the neighbouring farms.

When it comes to the cost function, we use the Symmetric Generalized McFadden (SGM) cost function, which is similar to the one used in Weick and Heckelei (2007), and we therefore keep the discussion fairly brief. One advantage of such a function is its flexibility as it is based on the second-order approximation of an unknown function. In addition, it allows us to include zero output quantities, which is a common situation in all multi-output studies using micro data.[1] The functional form is as follows:

$$\begin{aligned} C &= (\theta'W)a'Yt + (\phi'Y)b'Wt + Y'CW + Z'DW(\phi'Y) + \\ &+ \frac{1}{2}(\theta'W)^{-1}W'EW(\phi'Y) + (\theta'W)\{Z'FZ + Y'GY + Z'HY + \\ &+ \sum_m y_m (Y'Q_m Y)\} + (\theta'W)(\phi'Y)m'S, \end{aligned} \tag{2}$$

where Y is a vector with output quantities, W a vector of input prices, Z a vector of quasi-fixed factors, t is time, S is a vector with shift-variables, and θ and ϕ [2]are column vectors with fixed-weights resulting in an input price and output quantity index, respectively. Parameters to be estimated are found in the column vectors *a*, *b* and *m*, as well as in the matrices *C*, *D*, *E*, *F*, *G* and *H*. To preserve theoretical consistency of our cost function (see Chambers, 1953), the vector of shifters is multiplied by output and input prices.[3]

The behaviour of the firms is such that they minimise costs by choosing an appropriate set of inputs given the quasi-fixed input and output quantities. This cost-minimising behaviour is made under the condition that farmers take both input and output prices for given, which means that we may use Shephard's (1953) lemma in order to derive the following input-demand equations:

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[1] The foundation of the used Symmetric Generalized McFadden (SGM) function is found in Diewert and Wales (1987), and different expansions of the SGM are found in Kumbhakar (1994), Peeters and Surry (2000) and Pierani and Rizzi (2003).

[2] $\theta_i = \sum_f x_{if} / \sum_i \sum_f x_{if}$ and $\phi_m = \sum_f p_{mf} / \sum_m \sum_f p_{mf}$, where x_{if} is input quantities and p_{mf} is output prices.

[3] See also Blank and Eggink (2001), which used a quality-adjusted cost function in order to examine the cost structure of the Dutch nursing home industry.

$$x_i = \frac{\partial C}{\partial w_i} = \theta_i a'Yt + (\phi'Y)b_i t + Y'C_i + Z'D_i(\phi'Y) +$$
$$+(\theta'W)^{-1}\{W'E_i - \frac{1}{2}\theta_i(\theta'W)^{-1}W'EW\}(\phi'Y) + \quad (3)$$
$$+\theta_i\{Y'GY + Z'FZ + Z'HY + \sum_m y_m(Y'Q_m Y) + \theta_i(\phi'Y)m'S\},$$

where the subscript is an input index and the observed input quantities (x_i) are equated with the optimal input quantities. In addition, in estimating this system of equations, several restrictions and regularity conditions are imposed on the estimated coefficients e_{ij}, g_{mn} and f_{kl}.[1] First, we impose symmetry on the coefficients in the matrices E, G and F. Next, we impose the adding up constraint on the matrix E, implying that the sum of e_{ij} over j inputs equals zero. Third, we impose positive semi-definiteness on G and F and negative semi-definiteness on E.[2] Finally, the marginal cost of product m is given by:

$$MC_m = \frac{\partial C}{\partial y_m} = (\theta'W)a_m t + b'Wt\phi_m + C'_m W + Z'DW\phi_m +$$
$$+\frac{1}{2}(\theta'W)^{-1}W'EW\phi_m + W'EW\phi_m + (\theta'W)\{Z'FZ\phi_m\} + \quad (4)$$
$$+(\theta'W)\{2Y'G_m + Z'H_m + 3Y'Q_m Y\} + \phi_m(\theta'W)m'S,$$

which is required to be non-negative, a restriction that can be imposed, if necessary, by the following reparametrisation of the calculated marginal cost (c_{m1}):

$$c_{m1} = \tilde{c}^2_{m1} - \min_{obs}\{[(\theta'W)a_m t + b'Wt\phi_m + C'_{m(-1)}W_{(-1)} + Z'DW\phi_m +$$
$$+\frac{1}{2}(\theta'W)^{-1}W'EW\phi_m + (\theta'W)\{Z'FZ\phi_m + Z'H_m\} + \quad (5)$$
$$+(\theta'W)2G'_m Y^{(m)}Q_m Y^{(m)} + \phi_m(\theta'W)m'S]/w_1\},$$

where the symbol $W_{(-1)}$ denotes the matrix W with the first row removed.

One implication of assuming profit-maximisation is that firms are supposed to have the same marginal cost as long as they face the same market price. However, the marginal cost may differ in a situation with restricted outputs, as discussed in Wieck and Heckelei (2007). This is the situation of milk farmers in Sweden, since production is subject to a national quota which is distributed among the Swedish farmers. As all milk farmers have received a share of the national quota since Sweden became an EU member, both inefficient and efficient farmers have the possibility of supplying milk to the dairies. Consequently, the cost structure and even the marginal cost may differ among farmers. Some farms may even face a shrinking marginal cost that decreases with increasing output since they cannot fully utilise their scale due to the quota restrictions.

[1] Note that subscripts *j* and *i* refer to variable inputs, *m* and *n* to outputs and *k* and *l* to fixed inputs.

[2] The concavity of the cost function in input prices is imposed by defining E as the product of its Cholesky factors L_E and L'_E and $E= -L_E L'_E$. Similar restrictions are imposed on F and G (i.e. $F= L_F L'_F$, $G= L_G L'_G$).

Data

The dataset used to evaluate differences in cost structures due to the provision of landscape services is compiled with information from two sources. One source is called TUVA, which is a Swedish database containing biological and cultural values of meadows and pastures. A more detailed discussion of this database is found in Waldo *et al.* (2009). The other is the Swedish FADN (Farm Accountancy Data Network), which contains several important economical variables. The information stemming from these databases are linked with the help of the Swedish farm register and a register of agricultural blocks.

Environmental quality indicators

The focus of the analysis is biodiversity measured as the number of species present in the pastures provided by the farmers (see Waldo *et al.*, 2009 for a discussion on the indicators). Our benchmark measurement of biodiversity on farm level is a weighted average of a simple headcount of the number of biodiversity-indicator species on each pasture:

$$I_1 = \sum_p^P s_p \left(\sum_j^J R_j^p \right), \qquad (6)$$

where R is a dummy taking the value of one if the indicator species j is found in pasture p or zero otherwise, J is the total number of indicator species, s_p is the share of total valuable hectares allocated to pasture p, and P is the farm's total number of parcels of valuable pastures. I_1 is an average level of biodiversity in the parcels of pastures found at each farm, which range from 1 to 39 parcels with a mean around 8. This measure may be viewed as a special case of a *biological benefit function* specified by e.g. Arponen et al. (2005), Moilanen (2007), and van Teeffelen et al. (2008). The biological benefit function implies that the importance of each species is considered:

$$I_2 = \sum_p^P s_p \left(\sum_j^J w_j R_j^p \right), \quad w_j = \frac{1}{\sum_p R_j^p}, \qquad (7)$$

where the only difference from the equation above is that each indicator species is weighted with its relative importance in Sweden. Species present in many pastures, i.e. commonly found species, will have a low weight and thus add less to the biodiversity indicator than rarer species.[1]

The biodiversity variable is constructed with the help of an inventory of environmental and cultural values of Swedish agricultural land used for semi-natural grazing (the TUVA database). The inventory was made between 2002 and 2004 on 48 527 different parcels of land, which summed up to over 300 000 hectares). The focus of the TUVA database is on the presence of vascular plants, and around 420 000 vascular plants were registered during the field studies. In total 69 species of vascular plants were systematically collected, and 60 of these indicate that the environmental service is of a high quality (high degree of biodiversity) while the remaining 9 indicate low quality. Only species indicating high

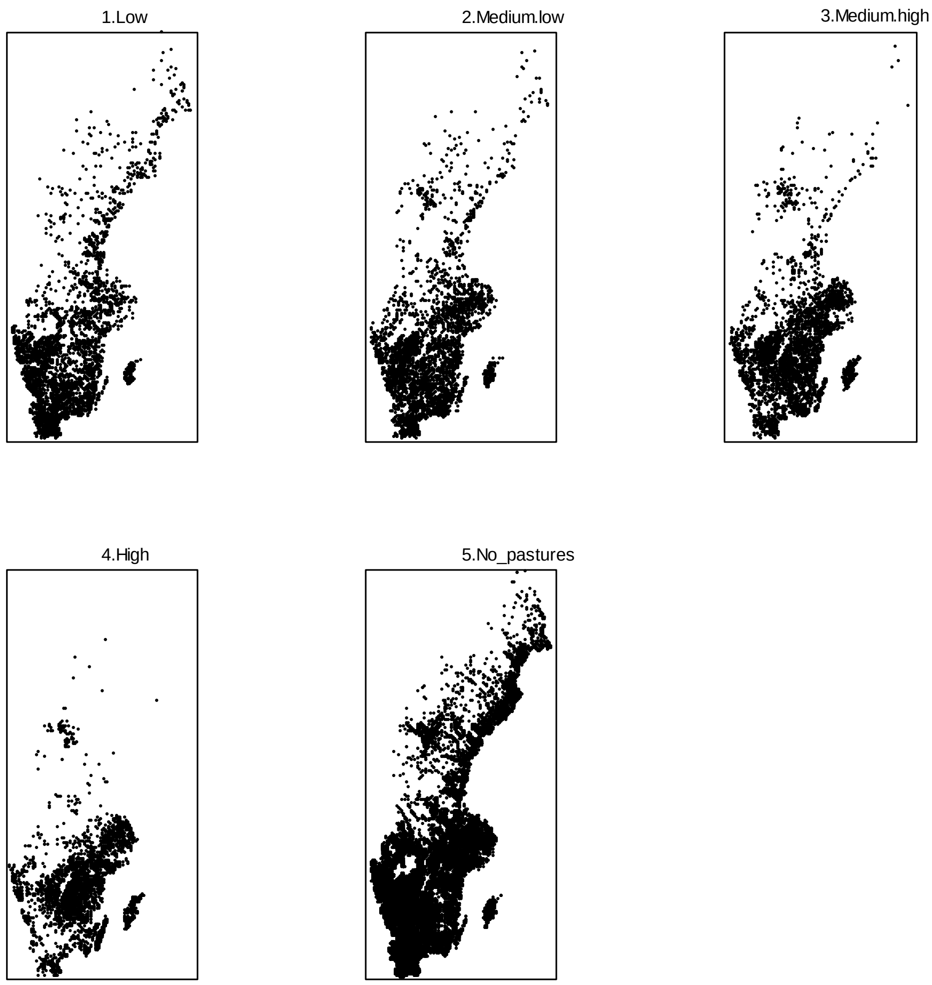
[1] An alternative way of determining *w* is found in Arponen et al (2005), who use the red-listing and regional rarity as a base for determining *w* where rarer species get a higher weight.

quality are used in our biodiversity indicators. The most common species is *Lady's Bedstraw* (Galium Verum, "gulmåra") which is present in more than 20 000 pastures. The correlation between the I_1 and I_2 indicators is 0.58.

All 48,527 parcels of land have been linked to an individual farm using a database on all Swedish agricultural blocks and the Swedish farm register of 2003. Thus, we may identify not only the location of each farm with valuable pastures, but also the environmental services provided by each farm. These farms add up to almost 20,000 while the rest of the Swedish farms (about 40,000) have no valuable pastures in the TUVA database. Figure 1 splits all farms into different categories when it comes to the provision of biodiversity according to the quality indicator I_1; (1) high, (2) low, (3) medium high, (4) medium low and (5) no values. Groups 1-4 are defined as quantiles and consist of approximately 5,000 farms each. One interesting observation is that the provision of biodiversity seems to be spatially dependent, as low values are more prominent in the southern part of Sweden while the high values are found in the plains region of Götaland. Such a spatial interdependence (e.g. due to biological factors) is also underscored in Wossink and Swinton (2007). We formally tested the null hypothesis of no spatial dependence, using Moran's I test, which compare the observed spatial pattern with a random one. The test statistic was around 0.738, which indicates a spatial dependence.[1]

[1] See Anselin (1988) for a discussion on Moran's I.

Figure 1: The spatial distribution of biodiversity provision.



Economic variables

The economic variables are from the Swedish FADN-dataset 2003, which contains detailed information on a stratified sample of approximately 1,000 farms. It should be noted that the dataset is biased towards larger farms in order to represent the majority of the total output in Sweden. In addition, we restrict the sample to milk farmers, which leaves us with 304 farms. The descriptive figures for these farms as well as the variables used in our system of equations are found in Table 1. The shares of milk sales range from 20 to 89 per cent with an average around 67 percent, which suggests a rather heterogeneous group of farmers. The other sales considered in this study are crop and beef sales. The variable inputs consist of animal specific costs (e.g. feed, veterinary fees, milk tests), crop-specific costs (e.g. seeds, crop protection and fertilisers), and other variable costs (including e.g. paid labour, fuels and current costs). The quasi fixed inputs included in the model are livestock (livestock units), total agricultural area used and unpaid work by family members.

The number of positive, for the biodiversity, species on each farm ranges from 0 to 21 with an average of 4. The reason for zero biodiversity is that 134 out of 304 milk farmers lack permanent pastures. Accordingly, we use two different sample sizes in our study. First, we use the full number of milk farmers (i.e. 304) represented in FADN when we estimate the cost function without any information on biodiversity. Second, we use milk farmers with permanent pastures (i.e. 170) when we analyse the relationship between costs and the provision of biodiversity.

Table 1. Variables, definitions, sources, units, means and standard deviations

	Variables	Definition, source, units	Mean	Std.dev.
Inputs				
X1	Animal specific costs	Expenditure weighted average, FADN, SEK	589,680	632,514
X2	Crop specific costs	"	86,501	95,874
X3	Other variable costs	"	797,050	946,020
w1/w2/w3	Prices	Expenditure weighted average within each category, SBA, price indices	1.02/1.09 /1.10	0.01/0.02 /0.01
Outputs				
Y	Total output	Sales and use weighted average, FADN, SEK	1,536,333	1,612,893
Y1	Crops	"	339,095	426,801
Y2	Milk	"	973,480	1,108,633
Y3	Beef	"	136,151	158,208
Py/Py1/Py2/Py3	Prices	Sales weighted within each category, FADN, unit values (price per tonne)	0.98/0.90/ 1.01/0.97	0.09/0.17/ 0.12/0.18
Quasi-fixed inputs				
Z1	Livestock	Total number of livestock units, FADN, livestock units	78	90
Z2	Agricultural area	Total utilised agricultural area, FADN, hectares	90	91
Z3	Unpaid labour input	Time worked by unpaid labour, FADN, hours	3,973	1,822
Biodiversity				
I_1	Biodiversity index 1	Number of species, TUVA, count	4.3	5.2
I_2	Biodiversity index 2	Weighted number of species, TUVA, count	0.0008	0.0010
I_3=I_1(w_rook2)	Spatially weighted biodiversity index 1 using a rook matrix with neighbours and neighbours' neighbours.	Average number of species provided by neighbours, TUVA, count	2.9	2.7
I_4=I_2(w_rook2)	Spatially weighted biodiversity index 2 using a rook matrix with neighbours and neighbours' neighbours.	Average number of species provided by neighbours, TUVA, count	0.0006	0.001
Number of farms	304			

Notes: Sources are; SBA is the Swedish Board of Agriculture, FADN is the Swedish Farm Accountancy Data Network, and TUVA is the Swedish Board of Agriculture biodiversity investigation.

Results

Cost distribution and biodiversity

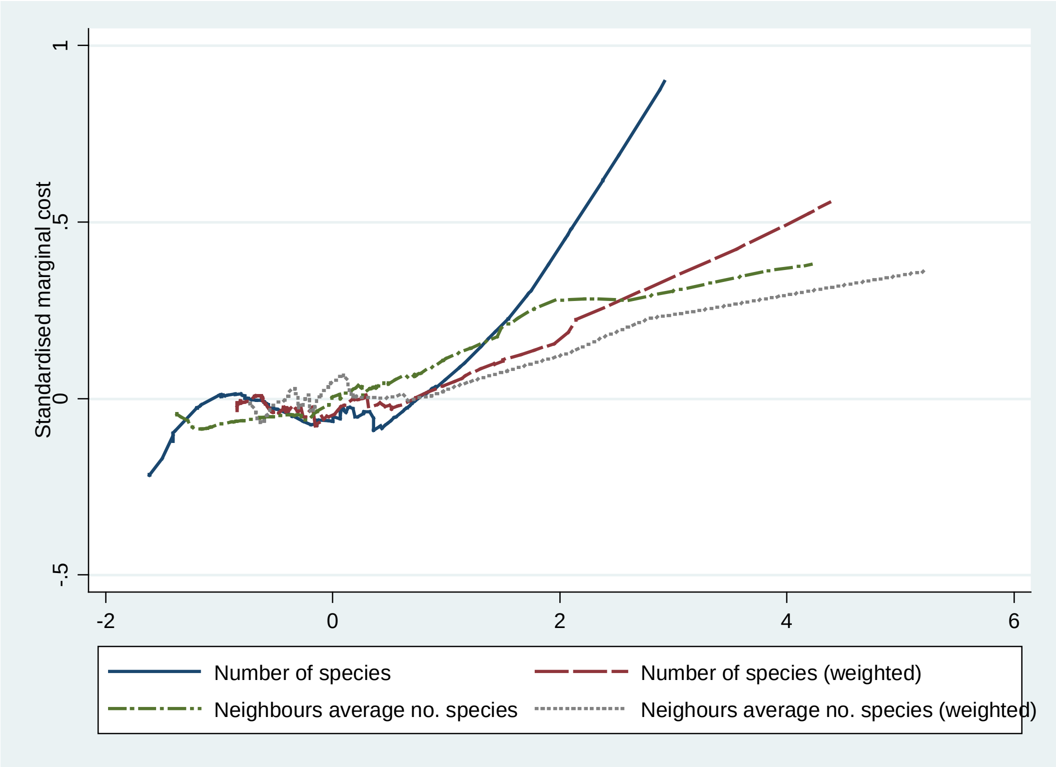
Our first step is to estimate the cost function using the complete set of milk farmers (i.e. 304 farms), which can be found in the appendix (table A1). The fit of the model is very good since more than 70 per cent of all coefficients are significant at a five per cent level and the R-squared range between 0.81 and 0.97. The estimate includes a cost shifter (the longitude of the farm) in order to capture differences in technology and climate depending on where the farm is located in Sweden. This shifter is significant and implies that the cost level is higher the further north the farm is located. Finally, the marginal costs are always positive.

The first set of results is found in Figure 2, which shows the relationship between different measures of biodiversity (I_1 and I_2 discussed above) and the marginal cost. This is done by a non parametric estimation approach using locally weighted least squares on standardised variables. The analysis focuses on those farms that have valuable pastures. The results show that we have a positive relationship between marginal costs and the different measures of biodiversity on farm level as well as on neighbouring farms. That is, farms providing a relatively large amount of biodiversity by keeping important pastures open have a higher cost level. Nonetheless, the relationship is not strong when we consider low levels of biodiversity since the increased costs take off after a threshold level around the mean provision of biodiversity. If we compare the different measures, we can see that the relationship is stronger when we only consider the number of species without using weights indicating the importance of each species. In addition to farm level biodiversity, we also find a positive relationship between marginal costs and neighbours' provision of biodiversity (using I_3 and I_4 with a spatial rook-weight including two levels of neighbours).[1] This relationship is less pronounced, though, compared to the farm level.

In order to evaluate whether the relationship in Figure 2 is robust, we investigate whether it holds in a multivariate regression including regional dummies (splitting up Sweden into more than 60 regions), a dummy indicating whether the farm is an organic one or not, and a variable indicating the number of parcels of permanent pastures found on farm level.

[1] Rook-weight with two levels of neighbours implies that we consider each farm's adjacent neighbours as well as the adjacent neighbours of these neighbours. The results are very similar when we only use neighbouring farms and hence exclude neighbours' neighbours.

Figure 2. Relationship between marginal costs and biodiversity (using locally weighted least squares and standardized variables)



Notes: *Number of species* and *Number of species (weighted)* relate to measure I_1 and I_2 respectively. The average provision of neighbours is measured by I_3 and I_4.

The results are found in Table 2, which presents the coefficients from six regressions (one per row) using different measures of biodiversity provision. In short, the results support the relationship found in Figure 2. High levels of biodiversity on individual farms as well as on neighbouring farms are related to a higher marginal cost even when we control for the localisation of the farm with regional dummies, whether the farm is organic or not, and the number of permanent pastures on each farm. This is valid for all measures but one. The first regression (regression 1 in Table 2) incorporates all milk farmers and assesses the difference in marginal costs between those with at least one parcel of permanent pasture and those without. The result indicates that farms managing valuable land areas have a higher cost structure although the impact is rather modest. The elasticity is around 0.06, which implies that the marginal cost is on average 0.06 per cent higher for farmers with valuable lands compared to those without.

However, regressions 2-5 show that the cost structure does not only change when managing valuable land, it also increases with the number of parcels of pastures and with amount of biodiversity provided. If a farm adds another parcel of permanent pastures, then the marginal cost increases by 0.05 percent. If a farm provides 1 percent more biodiversity, the marginal cost increases with 0.03 percent. A comparison between the different biodiversity indices reveals that the relationship is weaker with the weighted biodiversity index (I_2) than with the unweighted one (I_1). Hence the cost structure is not worse for those farms with the most valuable species. Finally, the importance of the locality is underscored by a positive relationship between the provision of neighbouring farms and marginal costs (I_3 and I_4).The exception, however, is regression 4, which indicates that a marginal increase of the number of hectares of pastures does not change the cost structure but only as long as we control for the number of pastures. Otherwise we find a positive relationship.

Table 2. The relationship between marginal costs and biodiversity

Regression model	Biodiversity measure [a]	Organic	Number of pastures	R-squared / Observations
1: Dummy indicating whether the farm has valuable land or not	1.98 (.00) {.059}	2.68 (.00)		0.18 / 7,749
2: No. of species (I1)	0.07 (.00) {.029}	2.22 (.00)	0.26 (.00)	0.29 / 4,429
3: No. of species weighted (I2)	62.3 (.00) {.004}	2.37 (.00)	0.27 (.00)	0.29 / 4,429
4: Hectares of valuable permanent pastures	~0 (.91) {0.0001}	2.41 (.00)	0.27 (.00)	0.29 / 4,429
5: Average no. of species provided by neighbours (I3)	0.12 (.00) {.024}	2.31 (.00)	0.26 (.00)	0.29 / 4,429
6: Average no. of weighted species provided by neighbours (I4)	240.17 (.02) {.011}	2.36 (.00)	0.26 (.00)	0.29 / 4,429

Notes: All regressions use weights in order to consider how many farms each observation represents and include regional dummies. [a] We present coefficients, p-values in parentheses, based on robust standard errors, and elasticities in curly brackets.

We further investigate the relationship between marginal costs and the provision of biodiversity at the farm level versus the provision of neighbours by incorporating them in a regression. The two measures are, however, highly correlated, which is indicated by high correlation coefficients (ranging between 0.56-0.71). Hence, the regressions with both measures result in insignificant coefficients. An additional specification is to add an interaction term between farm and neighbours' provision of biodiversity in order to investigate any non-linearity between these variables. A possible non-linear relationship between these variables is indicated by Figure A1 in the Appendix, which shows that a higher marginal cost is associated with a higher farm-provision of biodiversity and that this relationship is strengthen by a higher neighbourhood-provision of biodiversity.

This relationship is tested in Table 3, which differs from the specification in Table 2 by including both the farms' and the neighbours' provision of biodiversity as well as an interaction between these two variables. Since one may suspect that a few observations with relatively high levels of marginal costs (see Figure A1) could influence the results, we present the results with and without an outlier dummy (consisting of five farms with a relatively high marginal cost). The most important result from this specification is that the interaction term is positive in all regressions, suggesting that the marginal costs, given the level of provision at the farm level (by neighbours), increase when the supply of biodiversity is increased by neighbouring farms (at farm level).

Table 3. The relationship between marginal costs and biodiversity

	No. of species (I1 or I3)	No. of weighted species (I2 or I4)	No. of species (I1 or I3)	No. of weighted species (I2 or I4)
Farm level biodiversity (I1 or I2)	-.05 (.17)	-327 (.00)	-.06 (.01)	-463 (.00)
Average biodiversity provision by neighbours (I3 or I4)	-.16 (.01)	-193 (.18)	-.06 (.26)	329 (.00)
Interaction between farm and neighbour provision of biodiversity	.02 (.00)	64 (.00)	.02 (.00)	73 (.00)
Elasticity of farm level provision	{.027}	{-.026}	{.018}	{-.037}
Elasticity of neighbours' provision	{.013}	{-.009}	{.032}	{.015}
Outliers (marginal cost > 40)	no	no	yes	yes
Organic and number of pastures	yes	yes	yes	yes
Regional dummies	yes	yes	yes	yes
R-squared	0.29	0.29	0.61	0.62
Nobs	4,429	4,429	4,429	4,429

Notes: All regressions use weights in order to consider how many farms each observation represent. The p-values in parentheses are all based on robust standard errors.

The elasticities of the biodiversity measure at farm and neighbours' levels (including the indirect effects) are in line with the results in Table 2 when we use the unweighted biodiversity measure. That is, they both increase the marginal cost and the impact is around 0.001-0.03 per cent when we increase biodiversity by 1 per cent. If we use the weighted measure, the result is less clear since we find a negative impact when it comes to the biodiversity at farm level, and an ambiguous result when it comes to the biodiversity on neighbouring farms. The ambiguity is due to some outliers, and when we include a dummy for these farms we find a positive relationship between marginal costs and the provision of biodiversity by neighbouring farms.[1]

The final step in this section is to assess the relationship of biodiversity and the marginal costs of crops, milk and beef separately. The estimated cost function is found in the Appendix Table A2, which does not include the cost shifter (longitude). The reason for this is that the flexible cost function with several outputs considers technological differences due to climate through differences in output compositions at farm level. The goodness of fit of the model is high, which is indicated by a high share of significant coefficients (around 77 per cent) and high R-squares. When it comes to the relationship between the marginal costs and biodiversity, the results repeat the findings discussed above. Farms managing valuable pastures do have higher marginal costs, and the costs increase with the provision of biodiversity.[2] The additional finding in Table 4 is that the relationship differs across products. The impact of providing biodiversity is larger for milk than for crop production, and higher for beef compared to milk production. If the farmer increases biodiversity by 1 per cent, then the impact on the marginal costs of crops is insignificant, while the impact on the marginal costs of milk and beef is around 0.04 percent and 0.10 percent respectively.

Table 4. The relationship between output-specific marginal costs and biodiversity

	Dummy indicating whether the farm has valuable land or not	No. of species (I_1)	No. of species provided by neighbours (I_1_*rook2*)
Marginal costs for crops	{.06}	n.s	n.s.
Marginal costs for milk	{.12}	{.04}	{.04}
Marginal costs for beef	{.30}	{.10}	n.s.

Notes: Each elasticity is based on a single weighted regression, just as in Table 2 and 3, of a product-specific marginal cost on one of the biodiversity variable, an organic dummy, the number of valuable pastures and regional dummies. The abbreviation n.s. indicates insignificance (i.e. a p-value greater than 0.1).

[1] Note that the qualitative results in Table 2 do not change when we include the same outlier dummy. Nonetheless, the impact is reduced by around 50 per cent for all variables.
[2] Table 4 only includes, in order to save space, the elasticity of each product-specific marginal cost with respect to changes in a biodiversity variable. The relationships between the different marginal costs and organic farming as well as the number of pastures are still positive and significant as in the analyses of Table 2 and 3. All results are however available upon request.

Biodiversity as an output

Our second approach is to incorporate biodiversity as an output, which implies two new variables. First, we consider the total provision of biodiversity by multiplying index I_1 with the number of permanent pastures, instead of only focusing on the average number of species provided by the farm's pastures. Second, the approach used means that we need a price for biodiversity in order to calculate the output weights in equation (2). Since we do not have the price of biodiversity, we approximate this by the inverse of the farm longitude. The reason for this is that the yield is lower further north, which indicates a lower opportunity cost.[1] We also estimate the cost function when we only incorporate total output (see Table A3 in the Appendix) and when we incorporate several outputs (see Table A4 in the Appendix).

This approach allows us to evaluate the relationship as defined by Havlik (2008) since we are able to calculate whether the marginal costs of market commodities increase or decrease with biodiversity. The former situation implies a competitive relationship while the latter suggest a complementary relationship. The results in Table 5 are unambiguous. More biodiversity is always related to a higher marginal cost regardless of whether we focus on total costs or different outputs such as crops, milk and beef. The impact is, however, rather modest in most cases since the elasticities are low. The only significant impact, when it comes to levels, is on marginal costs for milk and beef, like our findings above. A one per cent increase in biodiversity is related to a 0.07 and 0.06 percent increase in the marginal costs of milk and beef production.

Table 5. Marginal costs based on the cost functions in Table A3 and A4 in the Appendix

Marginal costs	Total	Bio-diversity (I_1)	Crops	Milk	Beef	Bio-diversity (I_1)
Mean	17.95	2.85	6.57	0.51	1.72	0.39
Standard deviation	8.11	0.89	0.47	0.26	0.72	0.22
Elasticity w.t.r. of own output	0.06		1.6e-8	0.11	0.03	
Elasticity w.t.r. of biodiversity	0.002	0.0002	~0	0.07	.06	0.33

Notes: The elasticities are the mean elasticity of all observations.

An interesting finding was that the economies of scope (defined as in Khumbhakar, 1994) was very close to one in both cases (Table A3 and A4), which implies no efficiency from specialisation as was found in Peerlings and Polman (2004). The economies of scope found

[1] We have also used the same price for all farms (i.e. all farm prices of biodiversity equal one) but the qualitative results do not change.

in the sample used in this study was 0.99 with only total output and farm provision of biodiversity while it was 0.98 when we used three outputs instead of total output.

Finally, similar relationships are found when we use the alternative biodiversity measure (I_2) and when we incorporate neighbours' average provision of biodiversity as a cost shifter. Neighbouring provision of biodiversity is also found to be positive in this setting, which implies that the cost structure is higher for firms in a local environment with high biodiversity values. This impact is, however, only significant when we only consider total output and not when we decompose total output into three different outputs.

Conclusions

This study uses information on the economic performance and biodiversity provision of 304 Swedish milk farmers to report research on the relationship between biodiversity and the cost of farming. The biodiversity indicators are based on biological field studies mapping the existence of valuable species in the agricultural landscape, while farms' marginal costs are estimated using a flexible cost function.

We find a positive correlation between marginal costs and biodiversity. This relationship is valid when it comes to the binary choice of managing permanent pastures or not, and to providing more biodiversity for those already with valuable pastures. For the main indicator - number of species of vascular plants – a one percentage increase in biodiversity is related to a 0.03 per cent higher marginal cost. If we instead incorporate biodiversity into the farm cost function and assume it to be a variable output, then we also find that an increase of biodiversity boosts marginal costs. Our results therefore support a competitive relationship between the provision of biodiversity and farms' cost structure. This also holds for different types of outputs, but it is more pronounced between biodiversity and beef production.

Weighting the number of species with rarity gives a similar but somewhat weaker relationship, which suggests that the landscape characteristics of pastures with rare species are not more unfavourable for modern agricultural production than other pastures. However, from a biological perspective, the landscape properties are of course important for biodiversity, not least the possible networks of habitats. If a pasture is not grazed for a number of years, many species will be lost, but, with surrounding pastures containing the species, a re-colonization is possible. A further examination of the biodiversity at neighbouring farms shows that farms located in areas where neighbours have high biodiversity will on average have higher costs than other farms. The elasticity is similar to that of biodiversity at the own farm, a possible explanation being that landscape characteristics influence both biodiversity and the farmers' cost structure.

These findings question the efficiency of the support scheme of today since a flat rate per hectare fails to consider the diversity of biodiversity provision and its impact on farms' cost structure. In addition, the competitive relationship found in this study doesn't support the apprehension of a reduced provision of biodiversity, at least on the margin, due to a lower production in the footstep of a more decoupled common agricultural policy in the EU.

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Annex 1: Tables and Figures

Table A1. Estimated coefficients from a SGM cost function with total output and no biodiversity

Parameter in equation (2)	Coefficient (t-statistics)	Parameter in equation (2)	Coefficient (t-statistics)
c1_1	.203 (28.5)	e1_1	1.09 (112.)
c1_2	2.30 (61.2)	e2_1	.083 (77.1)
c1_3	2.59 (70.5)	e2_2	1.23 (125.)
d1_1	3.54 (85.5)	f1_1	-.03 (0.0)
d1_2	-.04 (-12.)	f2_1	.005 (0.0)
d1_3	-.39 (-30.)	f3_1	.022 (14.5)
d2_1	-.06 (-11.)	f2_2	.024 (0.0)
d2_2	.133 (19.8)	f3_2	.000 (0.0)
d2_3	.183 (16.4)	f3_3	-.01 (0.0)
d3_1	.131 (32.2)	g1_1	.068 (42.9)
d3_2	.439 (44.9)	h1_1	.010 (26.5)
d3_3	.438 (53.1)	h1_2	.000 (0.0)
		h1_3	-.00 (0.0)
		m1	.820 (68.7)

Equations	*Observations (weighted)*	*RMSE*	*R-squared*
X1	7749	1.668	0.97
X2	7749	5.816	0.81
X3	7749	5.791	0.81

Notes: 73 per cent of all coefficients are significant at the 5% level. The estimation is made with the following imposed restrictions; negative semi-definiteness of E and positive definiteness of F. Marginal costs are always positive with a mean of 17.99. The t-statistics are based on robust standard errors and we weight the regression with the number of farms each observation represents. Note that the RMSE and the R-squared of the cost function is not reported since we base our regression on the system of derived input demands.

Table A2. Estimated coefficients from a SGM cost function with three outputs and no biodiversity

Parameter in equation (2)	Coefficient (t-statistics)	Parameter in equation (2)	Coefficient (t-statistics)
a2	0.119 (25.2)	e2_2	0.912 (255.)
a3	-0.30 (-27.)	f1_1	0.081 (21.9)
c1_1	0.477 (68.3)	f2_1	0.009 (27.2)
c1_2	2.178 (209.)	f3_1	0.040 (30.5)
c1_3	2.416 (245.)	f2_2	0.000 (0)
c2_1	1.309 (62.0)	f3_2	0.118 (42.3)
c2_2	1.004 (77.3)	f3_3	0.378 (96.1)
c2_3	1.025 (143.)	g1_1	-0.06 (0)
c3_1	-0.23 (-41.)	g2_1	-0.00 (0)
c3_2	0.004 (0)	g3_1	-0.00 (0)
c3_3	0.177 (62.8)	g2_2	0.177 (31.4)
d1_1	0.503 (143.)	g3_2	0.548 (92.0)
d1_2	0.105 (93.2)	g3_3	-0.02 (0)
d1_3	0.096 (105.)	h1_1	-0.06 (-74.)
d2_1	0.000 (.00)	h1_2	0.001 (26.9)
d2_2	0.059 (.00)	h1_3	-0.22 (-70.)
d2_3	0.018 (.00)	h2_1	0.055 (53.5)
d3_1	0.000 (.00)	h2_2	0.043 (40)
d3_2	-0.04 (0.0)	h2_3	0.110 (30.0)
d3_3	0.000 (0.0)	h3_1	-0.06 (-54.)
e1_1	0.934 (0.0)	h3_2	-0.03 (-42.)
e2_1	2.154 (422.)	h3_3	-0.00 (0)
Equations	*Observations (weighted)*	*RMSE*	*R-squared*
X1	7749	1.443	0.98
X2	7749	4.437	0.89
X3	7749	4.348	0.89

Notes: 77 per cent of all coefficients are significant at the 5% level. The estimation is made with the following imposed restrictions; negative semi-definiteness of E and positive definiteness of F and of G. Marginal costs are always positive with a mean of 5.9, 0.7 and 1.5 for crops, milk and beef, respectively. The t-statistics are based on robust standard errors and we weight the regression with the number of farms each observation represents. Note that the RMSE and the R-squared of the cost function is not reported since we base our regression on the system of derived input demands.

Table A3. Estimated coefficients from a SGM cost function with total output and biodiversity provision

Parameter in equation (2)	Coefficient (t-statistics)	Parameter in equation (2)	Coefficient (t-statistics)
a2	.0489 (10.9)	e2_1	1.201 (92.7)
_1	.0000 (.00)	e2_2	.0247 (.00)
c1_2	1.311 (16.2)	f1_1	.0003 (.00)
c1_3	-.000 (.00)	f2_1	-.000 (.00)
c2_1	.3015 (28.4)	f3_1	.1196 (17.6)
c2_2	.3885 (26)	f2_2	.0031 (.00)
c2_3	.3670 (23)	f3_2	.1074 (15.0)
d1_1	.3669 (45.9)	f3_3	-.015 (.00)
d1_2	-.162 (-16)	g1_1	.7843 (97.7)
d1_3	-.090 (-19)	g2_1	.0087 (15.4)
d2_1	.1083 (22.6)	g2_2	-.034 (.00)
d2_2	.4967 (46.6)	h1_1	.0414 (23.0)
d2_3	.6314 (67.3)	h1_2	.0025 (8.15)
d3_1	.1774 (21)	h1_3	-.088 (-17)
d3_2	.4850 (20.2)	h2_1	.0017 (6.46)
d3_3	.5205 (28.4)	h2_2	-.039 (-36)
e1_1	.6727 (80.9)	h2_3	-.083 (-17)

Equations	*Observations (weighted)*	*RMSE*	*R-squared*
X1	4,429	2.19	0.96
X2	4,429	6.56	0.82
X3	4,429	6.99	0.79

Notes: 77 per cent of all coefficients are significant at the 5% level. The estimation is made with scaled variables and the following imposed restrictions; negative semi-definiteness of E and positive definiteness of F and G. Marginal costs are always positive with a mean of 17.9 and 2.85 for total output and biodiversity (measured by I_1 times the number of pastures), respectively. The t-statistics are based on robust standard errors and we weight the regression with the number of farms each observation represents. Note that the RMSE and the R-squared of the cost function is not reported since we base our regression on the system of derived input demands.

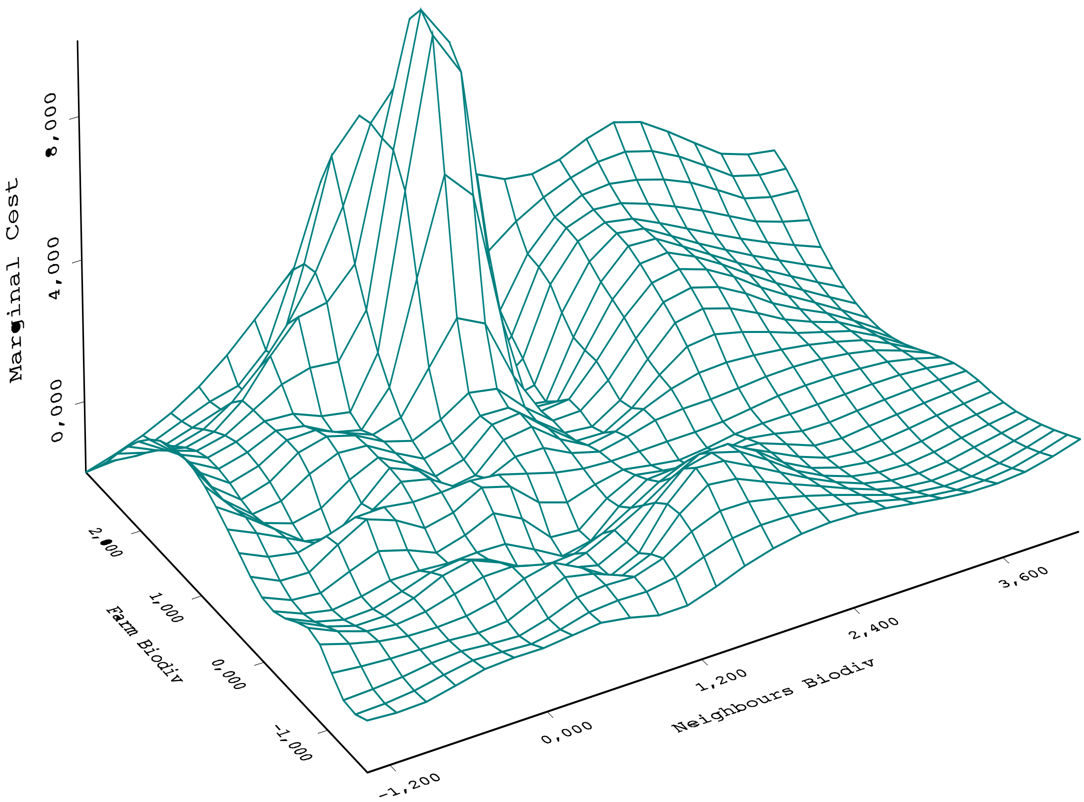
Table A4. Estimated coefficients from a SGM cost function with three outputs and biodiversity provision

Parameter in equation (2)	Coefficient (t-statistics)	Parameter in equation (2)	Coefficient (t-statistics)
a2	-.396 (-85)	f2_1	.019 (47.2)
a3	-.003 (.00)	f3_1	.091 (65.5)
a4	.8265 (102)	f2_2	.116 (49.1)
c1_1	.4776 (58)	f3_2	-.031 (-30)
c1_2	2.242 (230)	f3_3	-.036 (.00)
c1_3	2.451 (216)	g1_1	.0113 (.00)
c2_1	.3946 (28.9)	g2_1	.5786 (75.2)
c2_2	-.007 (.00)	g3_1	.1552 (74.0)
c2_3	-.492 (-82)	g4_1	.1099 (129)
c3_1	.0005 (.00)	g2_2	-.005 (.00)
c3_2	.2099 (48.4)	g3_2	-.013 (.00)
c3_3	-.006 (.00)	g4_2	.0052 (.00)
c4_1	-.085 (-21)	g3_3	-.001 (.00)
c4_2	-.002 (.00)	g4_3	.0036 (.00)
c4_3	-.007 (-27)	g4_4	-.001 (.00)
d1_1	.5190 (104)	h1_1	-.064 (-56)
d1_2	.1013 (65.8)	h1_2	-.032 (-59)
d1_3	.1645 (129)	h1_3	.0000 (.00)
d2_1	-.000 (.00)	h2_1	.0928 (58.4)
d2_2	.0003 (.00)	h2_2	.1025 (56.4)
d2_3	-.061 (-63)	h2_3	.2640 (56.9)
d3_1	.0009 (.00)	h3_1	-.079 (-44)
d3_2	.0203 (33.4)	h3_2	-.002 (.00)
d3_3	.0940 (78.8)	h3_3	-.001 (.00)
e1_1	.0319 (79.5)	h4_1	-.086 (-82)
e2_1	2.749 (206)	h4_2	-.000 (.00)
e2_2	.0011 (.00)	h4_3	-.063 (-26)
f1_1	.0933 (68.7)		

Equations	*Observations (weighted)*	*RMSE*	*R-squared*
X1	4,429	1.82	0.97
X2	4,429	4.67	0.91
X3	4,429	4.47	0.92

Notes: 62 per cent of all coefficients are significant at the 5% level. The estimation is made with scaled variables and the following imposed restrictions; negative semi-definiteness of E and positive definiteness of F and G. Marginal costs are always positive with a mean of 6.57, 0.52, 1.72 and 0.39 for crops, milk, beef and total biodiversity (measured by I_1 times the number of pastures), respectively. The t-statistics are based on robust standard errors and we weight the regression with the number of farms each observation represents. Note that the RMSE and the R-squared of the cost function is not reported since we base our regression on the system of derived input demands.

Figure A1. Relationship between unweighted biodiversity (number of species) on farm as well as neighbouring farms (the farm's neighbours and the neighbours' neighbours) and the marginal costs (based on the cost function in Table A3). All variables are standardized.



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