European Review of Agricultural Economics Vol **32 (4)** (2005) pp. 469–488
doi:10.1093/erae/jbi028

Multifunctionality of agriculture: an inquiry into the complementarity between landscape preservation and food security

Rolf Jens Brunstad

The Norwegian School of Economics and Business Administration, Bergen, Norway

Ivar Gaasland

Institute for Research in Economics and Business Administration, Bergen, Norway

Erling Vårdal

University of Bergen, Bergen, Norway

Received February 2005; final version received September 2005

Summary

Without support, the levels of agricultural public goods such as food security and landscape preservation would fall short of demand in high-cost countries. However, as demonstrated by Norway as a case study, the current level of support is disproportionate from a public goods perspective, and the policy instruments are badly targeted at the public goods in question. Because agricultural land is a major component of both food security and landscape preservation, giving rise to a high degree of cost complementarity between the public goods, it would be more efficient to support land-extensive production techniques than production *per se*.

Keywords: food security, landscape preservation, public goods, jointness, agricultural policy

JEL classification: Q18, Q26

1. Introduction

It is widely accepted that there are externalities and public goods related to agricultural activity, such as the amenity value of the landscape, food security, preservation of rural communities and rural lifestyle (see Winters, 1989–1990; OECD, 2001; and more recently Hediger and Lehman, 2003). What implications these externalities should have for national agricultural policy is a more controversial issue. What support levels can be defended by the so-called multifunctional role of agriculture, and what policy instruments are efficient? In the current WTO negotiations, for example, some high-cost countries have used the multifunctional aspect to argue for continued high support levels, even in the form of tariffs and output subsidies. Low-cost countries reject such arguments as protectionism. The latter view finds support in a recent contribution from Peterson *et al.* (2002), who derive the efficient set of policies for a multifunctional agriculture, and show that efficiency cannot be achieved through output subsidies.

This paper offers an empirical contribution to the debate on the multifunctional aspects of agriculture. In earlier papers, we have examined the food security and landscape preservation arguments as separate issues. In Brunstad *et al.* (1995a), the food security argument was discussed. A numerical model was applied to compute what Norwegian agriculture would look like if the only purpose of support was to provide food security. Compared with the actual activity in agriculture, the analysis indicated a decline in employment and land use of about 50 per cent. Brunstad *et al.* (1999) dealt with the landscape preservation argument. A method for incorporating information on the willingness to pay for landscape preservation, as inferred from contingent valuation studies, was presented and implemented in the objective function of the model mentioned above. To illustrate the method, Norwegian agriculture was used as a case study, and optimal levels of production, land use, employment and support were calculated. Based on various simulation experiments, it was shown that only a minor fraction of today's generous support level would be maintained, and production and employment would drop to low levels. However, even if the landscape preservation argument was not able to defend today's levels of production and employment, it was strong enough to keep a substantial part of today's agricultural area under cultivation.

In this paper, we discuss the optimal policy when food security and landscape preservation are simultaneously taken into account. To what degree are these public goods complementary in the sense that supplying one of them more or less automatically would lead to supply of the other(s)? How much support is necessary to sustain reasonable levels of public goods, and what policy instruments are efficient, when cost complementarities are considered?

It should be noted that the focus is on high-cost countries such as Norway. In a pure free-trade equilibrium with no subsidies, essentially no food would be produced domestically. The levels of agricultural public goods would, therefore, also be close to zero.

In Section 2, we demonstrate some basic principles regarding food security, landscape preservation and cost complementarities within a simplified framework. In Section 3, these principles are elaborated in a richer model. A willingness-to-pay function for landscape preservation and a production function for food security are incorporated into a sector model for the agricultural sector in Norway. In Section 4, the model is used to analyse the optimal policy and supply of public goods when cost complementarities are considered. Section 5 offers concluding remarks.

2. Agricultural public goods: concepts and principles

2.1. Food security

The ability to provide food under all contingencies is referred to as *food security*. Food security can, following Ballenger and Mabbs-Zeno (1992), be defined on a global, national and individual level.

Global food security is defined as

$$Pr[(\text{world production} + \text{world stocks}) \geq \text{world needs}] \geq \pi \qquad (1)$$

where Pr symbolises probability, π is the minimum acceptable likelihood and 'needs' is the necessary consumption. This means that the sum of world production and stocks in every year must exceed the necessary consumption by a minimum acceptable likelihood.

National food security, formulated as

$$Pr[(\text{domestic production} + \text{domestic stocks} + \text{imports} + \text{aid}) \geq \text{domestic needs}] \geq \pi \qquad (2)$$

is less restrictive, as consumption can be based on imports and aid from other countries. Therefore, even if global food security is below reasonable limits, rich countries such as Norway will normally have enough purchasing power in world markets to secure a sufficient share of world production. The same logic applies to individual food security, which can be secured if a person has enough income or purchasing power, even if the nation's food supply is insufficient.

It follows that if global food security is fulfilled, then national and individual food security is a matter of distribution or poverty relief. A special case is a blockade in connection with war, which rules out distribution between countries (infinite import prices), e.g. as in the situation during World War II. This traditional argument for national food security seems to be outdated thanks to strong defence alliances and the way modern warfare is pursued. Nevertheless, it seems unwise to dismiss totally the need for a minimum of activity within the agricultural sector to diminish the negative effects of unknown crises in the future.

A more rational argument concerns global food security. Some kind of ecological crisis or man-made disaster (such as the Chernobyl fall-out) is less likely to be detrimental to global food security if production capacity is spatially diversified throughout the world. Although rich countries would be able to finance the high food import bill under adverse situations, it can be argued, for ethical reasons, that most countries should contribute to the global production potential. As agreed by a vast majority of economists, this is not an argument for national self-sufficiency.[1] Import tariffs and production subsidies are not only costly, but may also impair the purchasing power and food security in countries with comparative advantage in food production, e.g. many developing countries. It is, however, an argument for keeping necessary factors of production available with a minimum distortion on trade. In the forthcoming simulations, we will take the view that Norway should at least have the capacity to feed its own population if a crisis occurs.

2.1.1. The Gulbrandsen–Lindbeck principle

Gulbrandsen and Lindbeck (1973) attacked the self-sufficiency goal by stressing that production in normal times does not have to be equal to production during a crisis. Some switching of production when the crisis has arisen will be possible. The crucial condition for switching of production is, however, that the necessary factors of production are available, especially agricultural land but also skills, livestock and capital equipment.

The following simple example clarifies the Gulbrandsen–Lindbeck principle. We assume that we have two agricultural commodities X_1 and X_2 whose production only needs land, L. There is international trade in both commodities, so they can be bought and sold at world market prices $P^w_{x_i}$, $i = 1, 2$. The production technology is assumed to be Leontief, i.e.

$$X_i \leq \frac{1}{\gamma_i} L_i, \qquad i = 1, 2 \tag{3}$$

where γ_i is an input–output coefficient and L_i is the land used in the production of commodity i. Land is limited, i.e. $\sum_i L_i \leq \bar{L}$.

In Figure 1 we have drawn the production possibility frontier PP. The slope of PP equals $-\gamma_2/\gamma_1$.

Let us suppose that the necessary consumption in times of crisis, defined by a crisis menu, is given by $X^M = (X_1^M, X_2^M)$ shown as A. The land requirement for producing X^M is denoted L^M, and the production possibility frontier, given this land requirement, is the continuous line MM.

We assume that a level of land use is chosen that is not sufficient to guarantee complete food security. Thus we are only able to produce a share, λ, of the crisis menu. We define $X = (X_1, X_2) = \lambda X^M$. For the moment, we

1 Using an index of national food security, Sumner (2000) showed that trade barriers are detrimental to food security in most conceivable situations, mainly because of adverse effects on real income. Beghin *et al.* (2003) showed that the welfare costs for South Korea of pursuing food self-sufficiency (trade barriers) are substantial, and that food security can be achieved at much lower cost using more targeted policy instruments. An improved international trading environment, i.e. for agricultural products, is considered to stimulate economic growth, and thus strengthen food security, in developing countries that depend heavily on agriculture; see e.g. Anderson and Morris (2000), Davis *et al.* (2001) and Sumner (2000).

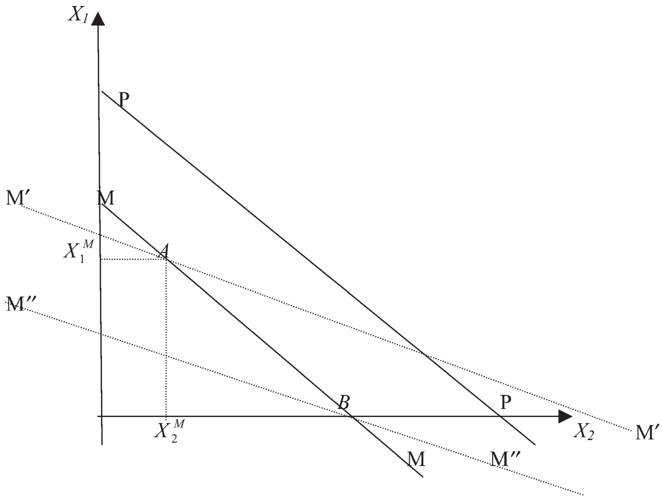

Figure 1. Production possibilities in the agricultural sector.

abstract from stockpiling and aid, and imports of the two commodities, ω_i, are treated as uncertain. Expression (2) can then be written as

$$Pr(X + \omega \geq \ X^M) \geq \pi; \quad \omega \geq 0 \tag{4}$$

where $\omega = (\omega_1, \mathrm{w}_2)$. $Pr(\lambda X^M + \omega \geq X^M) < 1$ for $\lambda < 1$, and the probability is 1 when $\lambda \geq 1$.

The point of departure for Gulbrandsen and Lindbeck is an inefficient agricultural sector. This means that the *net cost per hectare of land*, NCH_i, is positive:

$$NCH_i \equiv P_l - P_{x_i}^w \frac{1}{\gamma_i} > 0 \tag{5}$$

for both commodities. Without support, nothing will be produced.

Food security is an argument for agricultural support, i.e. land must be available when a crisis arises. Let us assume that it is more costly (per hectare) to produce X_1 than X_2, so $NCH_2 < NCH_1$, and that complete food security ($\lambda = 1$) is required.

The 'self-sufficiency principle' would imply production at A, at a cost corresponding to the line M′M′ (with a slope equal to $-NCH_2\gamma_2/NCH_1\gamma_1$). The Guldbrandsen–Lindbeck principle says that, in normal years, the most efficient way to guarantee the provision of L^M is to produce at the point marked as B, corresponding to the dotted line M″M″ going through this point.

Let us assume that we choose a level of food security equal to λ, $0 < \lambda < 1$, which corresponds to a level of land use equal to $L < L^M$. Given our assumptions, the minimum governmental cost, NC, for providing such a level of food security is given by

$$NC = NC(L) = [NCH_2]L. \tag{6}$$

For complete food security the net cost is $NC^M = NC(L^M)$.

2.2. Landscape preservation

An additional argument for agricultural support is the amenity value of the landscape. This is derived from an open and varied landscape, sustained by agricultural production. We follow Lopez *et al.* (1994) and assume the following willingness-to-pay function for landscape preservation:

$$WTP = \Theta[LP]^{\varepsilon} \tag{7}$$

where E (>0) is a constant, LP is an index of amenity-enhancing agricultural land that, in this section, we assume is equal to the use of land for agricultural production, L. ε reflects the marginal willingness to pay for landscape preservation and, because we assume $\varepsilon < 1$, the function in (7) satisfies the standard assumption that it is increasing and concave in LP.

If the amenity value of the landscape is the only external effect, the optimality condition is that agricultural production should expand until the marginal willingness to pay equals net cost per hectare, i.e.[2]

$$NCH_2 = MWTP \equiv \varepsilon\, \Theta L^{\varepsilon - 1}. \tag{8}$$

Figure 2 illustrates the optimal solution. The necessary rate of subsidy is shown as NCH_2. Because the available production techniques are Leontief, NCH_2 is a straight horizontal line until it reaches the limited amount of land, $\bar{L}$, where it turns vertical. The marginal willingness to pay for landscape preservation, $MWTP$, is given by the convex curve. Marginal willingness to pay is large when the agricultural activity is low, and diminishes with increased agricultural activity. The optimal land use equals L^{LP}.[3]

2.3. Cost complementarities

We assume now that, in addition to landscape preservation, complete food security is required. This means that L^M must be used to produce agricultural commodities. In Figure 2 it is assumed that $L^M > L^{LP}$. In this case, food

2 The condition is derived from the problem $\mathrm{Max}_{L_1,L_2}(P^w_{x_1}(1/\gamma_1)L_1 + P^w_{x_2}(1/\gamma_2)L_2 - P_l(L_1 + L_2) + \Theta(L_1 + L_2)^{\varepsilon})$, and we impose the assumption that $NCH_2 < NCH_1$.

3 In the case of a profitable agricultural sector, $\bar{L}$ is the optimal solution. Food security and agricultural landscape will then be provided freely as side effects from the activity in the agricultural sector.

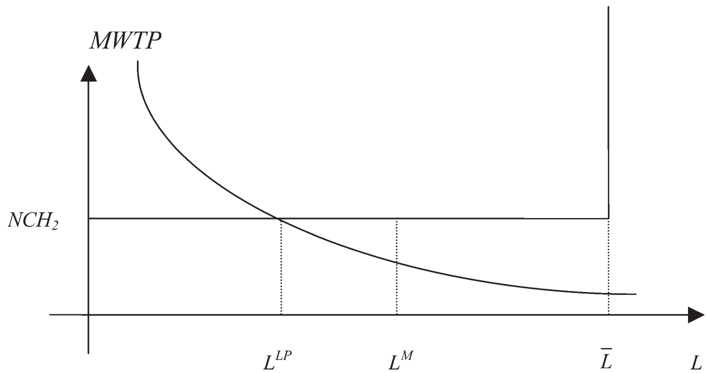

Figure 2. Optimal solution with public goods.

security dominates landscape preservation, and it is not optimal to use more land than L^M. Beyond this point the willingness to pay for landscape preservation falls far below the cost of production.

Figure 2 brings us to the concept of jointness in production. In general, joint production exists if the production of two or more outputs is interlinked in some way, e.g. through technical interdependencies or non-allocable inputs (see Boisvert, 2001). Jointness gives rise to cost complementarities, also referred to as economies of scope, which means that it is more expensive to produce the outputs separately than together.

For agricultural public goods, jointness is mainly related to the existence of non-allocable inputs. By definition, it is difficult to determine a non-allocable input's contribution to each output. In agriculture, land is the most obvious non-allocable input, because land enters into the production of both landscape preservation and food security, as well as private goods. But also labour and livestock have such characteristics. Besides being key inputs in food production, these inputs contribute to food security and they affect the amenity value of the landscape.

If we return to our simplified framework with land as the only input, $NC(L^M)$ gives the net stand-alone cost of providing food security. This relationship is shown in Figure 3a. As a result of our simple production technology, the net stand-alone cost curve of producing landscape preservation coincides with the cost curve drawn. If we use L^M in the production of food security and L^{LP} in the production of landscape preservation, the sum of the net stand-alone costs is $NC(L^M) + NC(L^{LP})$. In this case, the cost from joint production is $NC(L^M)$. The percentage increase in costs, if the production of the two goods is split up into separate processes, compared with joint production is then

$$c = 100\frac{NC(L^M) + NC(L^{LP}) - NC(L^M)}{NC(L^M)} = 100\frac{NC(L^{LP})}{NC(L^M)}. \quad (9)$$

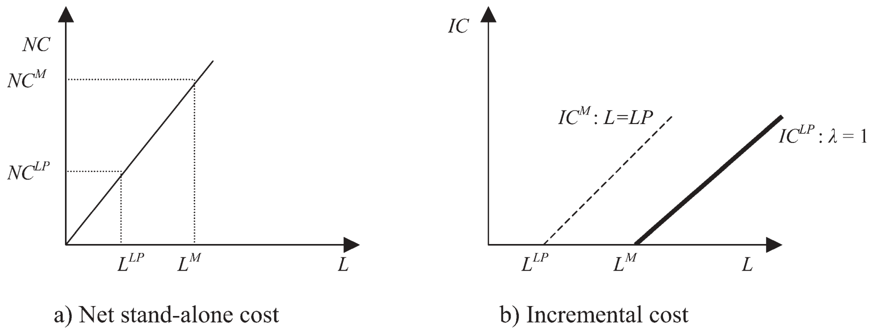

Figure 3. Cost curves for public goods. (a) Net stand-alone cost; (b) incremental cost.

Thus, c is a measure of the degree of cost complementarity between food security and landscape preservation, for given prices of private goods. If $c = 0$, there is no cost complementarity.

The existence of cost complementarities can also be visualised by reference to the incremental cost concept. The continuous line in Figure 3b illustrates the incremental cost of increasing the supply of landscape amenity values (IC^{LP}) if we have complete food security (L^M). Up to L^M, landscape values are produced freely. However, if society demands more landscape values, an incremental cost is incurred. Vica versa, the dotted line in Figure 3b is the incremental cost of producing food security (IC^M) for a given minimum level of landscape preservation, L^{LP}.

3. An agricultural model with public goods

To quantify the cost of providing public goods as well as cost complementarities, we need to elaborate the basic principles put forward in the previous section into a richer model. As a point of departure, we use a model of the agricultural sector in Norway.[4] This model is extended by incorporating a willingness-to-pay function for landscape preservation, and by adding a production function for food security.

3.1. The core model

The model, whose base year is 1998, covers the most important commodities produced by the Norwegian agricultural sector, in all 13 final and eight intermediary product aggregates. Of the final products, 11 are related to animal products whereas three are related to crops.

4 An early version of the model is described in Brunstad and Vårdal (1989), but the model has been considerably improved since then. A technical description of the model is given in Brunstad *et al.* (1995b). Details are given in Gaasland *et al.* (2001). The model is constructed to perform policy analyses, and has as such been used by the Norwegian Ministry of Finance and the Norwegian Ministry of Agriculture.

Inputs needed to produce agricultural products are land, labour (family and hired), capital (machinery and buildings), concentrate feed, and an aggregate of other goods. Furthermore, we distinguish between tilled land (T) and grazing on arable land and pastures (G), so that $G + T = L \leq \bar{L}$.

Domestic supply is represented by about 400 'model farms'. Each model farm is characterised by a Leontief technology, i.e. with fixed input and output coefficients. Although inputs cannot substitute for each other at the farm level, there are substitution possibilities at the sector level. For example, beef can be produced with different technologies (model farms), both extensive and intensive production systems, and in combination with milk. Thus, in line with the general Leontief model in which each good may have more than one activity that can produce it, the isoquant for each product is piecewise linear. Also, production can take place on small farms or larger, more productive farms. Consequently, there is a degree of economies of scale in the model.

The country is divided into nine regions, each with limited supply of different grades of land. This introduces an element of diseconomies of scale because, *ceteris paribus*, production will first take place in the 'best' regions.

Domestic demand for final products is represented by linear demand functions. Economic surplus (consumer surplus plus producer surplus) of the agricultural sector is maximised, subject to demand and supply relationships, policy instruments and imposed restrictions. The solution to the model is found as the prices and quantities that give equilibrium in each market. A broader description of the model is offered in the Appendix.

3.2. Landscape preservation

Landscape preservation is taken into account by adding the willingness-to-pay (WTP) function (7) to the economic surplus as defined in the previous paragraph. Obviously, it is hard to model all the attributes that enhance the value of the agricultural landscape, such as openness, variation, biodiversity and type of agricultural technique. Also, relevant WTP studies are scarce and based on controversial methods. In our approach, the amenity value of tilled land, T, is allowed to differ from that of grazing and pasture, G.[5] The aggregate for landscape preservation is postulated by the following CES function:

$$LP = \Lambda[\alpha_G\, G^{(\kappa-1)/\kappa} + \alpha_T\, T^{(\kappa-1)/\kappa}]^{\kappa/(\kappa-1)}. \qquad (10)$$

Following Brunstad *et al.* (1999), the parameters Θ, Λ, α_G and α_T are calibrated to estimates of amenity benefits taken from the research of Drake

5 In Brunstad *et al.* (1999), the amenity value of the landscape is treated as a regional public good. As the focus in this paper is on complementarities between landscape preservation and food security, we abstract from the spatial dimension and stick to the national level.

(1992). Based on the research of Lopez *et al*. (1994), the elasticity of scale, ε, is set equal to 0.172. This means that the marginal willingness to pay is strongly decreasing for rising levels of *LP*. Moreover, the elasticity of substitution between pasture and tilled land, κ, is assumed to be equal to 3.0, reflecting a relatively high degree of substitution possibilities.

3.3. Food security

Food security, *FS*, is represented in the model by the nested CES function:

$$FS = (\beta_L \, L^{(\sigma-1)/\sigma} + \beta_S \, S^{(\sigma-1)/\sigma} + \beta_A \, A^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)} \qquad (11)$$

where *S* is skilled labour and *A* is a CES aggregate of animal products, defined as

$$A = (\chi_M \, M^{(\mu-1)/\mu} + \chi_E \, E^{(\mu-1)/\mu} + \chi_C \, C^{(\mu-1)/\mu})^{\mu/(\mu-1)}. \qquad (12)$$

Here, *M* is meat products, *E* is eggs and *C* is cow milk. $\beta_i > 0$ ($\forall\, i = L, S, A$) and $\chi_j > 0$ ($\forall\, j = M, E, C$) are distribution parameters. σ and μ are the substitution elasticities in the first and second level of the function, respectively.

The function says that a certain level of food security can be obtained if certain levels of acreage, labour (i.e. agricultural skills) and animal production (i.e. livestock) are available. Furthermore, animal production is disaggregated into meat, eggs and milk. If we allow for positive substitution elasticities, then the same level of food security can be provided by different combinations of the various components. An important special case is when the substitution elasticities are set equal to zero. The CES functions in (11) and (12) then collapse into Leontief types.

To calibrate the distribution parameters of this function, we need to know the cost share (quantity and unit cost) of each of the components for a defined level of food security. In this respect, we use the crisis menu[6] in Table 1, and normalise the level of food security that corresponds to the crisis menu to $FS = 1$. The menu provides sufficient vitamins, minerals and proteins for the yearly subsistence needs of the population. If we take into account that there exist ample quantities of sugar through stockpiling, the menu also provides sufficient calories for the population. The palatability of the diet is reflected in a concern for minimising the difference between the crisis and the normal menus. Compared with normal consumption, the menu involves lower consumption of animal relative to plant products. Consumption of milk, meat and eggs is strongly reduced, whereas the consumption of grain and potatoes is kept at a relatively high level. In addition, the crisis menu

6 This table is taken from a government report (NOU, 1991, p. 142). The figures have been re-estimated to a 1998 level.

Table 1. Crisis menu compared with actual consumption in the base year 1998 (million kg per year)

	Consumption 1998	Crisis menu
Grains	463	335
Potatoes	309	461
Cow milk	1400	853
Meat	247	63
Eggs	44	17
Fish	72*	335

*Average consumption (product units) in the period 1995–1999 (Gaasland, 2003).

makes allowance for the fact that consumption of fish, for which Norway has a huge export surplus, can be considerably increased.[7]

The crisis menu indicates the minimum annual quantities of agricultural products that must be available for consumption in times of crisis. However, according to the Gulbrandsen–Lindbeck principle, production in normal times does not have to be equal to the necessary production during a crisis. Some switching of production when the crisis has occurred will be possible. This requires that essential factors of production are available, especially agricultural area, skills and livestock, as indicated by functions (11) and (12).

In line with the Gulbrandsen–Lindbeck principle, we first employ the agricultural model to calculate how much land (L_0) and labour (S_0) is needed to produce the quantities of food required by the crisis menu. These levels, calculated to be 56 per cent (L_0) and 29 per cent (S_0) of the base levels, must be kept continuously available in order to be prepared to produce the crisis menu if the need arises. In addition to keeping land and skilled labour available, livestock has to be available for meat and milk production. This limits the extent to which the current production of animal products can be reduced relative to the crisis menu. This is taken care of by assuming that the production of meat (M_0), cow milk (C_0) and eggs (E_0) must not fall below the levels of the crisis menu. Furthermore, if a crisis occurs, current import of grain will have to be replaced out of stocks for the time that is needed to cultivate the land such that sufficient grain can be produced. In Brunstad *et al.* (1995a) the stockpiling costs were estimated to be negligible compared with the production cost of grain.[8]

The quantities derived above are used to calibrate the distribution parameters of the function. However, to find cost shares we also need to know the unit cost of each component. Therefore, we impose a minimum restriction

7 Most of the fishing takes place in Norway's territorial water. In the period 1995–1999, the average exported quantity was 1,575 million kilograms, i.e. nearly five times the level of the crisis menu. Given Norway's long coastline, one would expect that fishing from coastal vessels should be sufficient to land the quantity of fish in the crisis menu.

8 The computation was based on the assumption that 4 years were needed to make enough land available to supply the quantity of wheat and coarse grain required by the crisis menu. Consequently, the necessary stocks needed to be twice the current level of imports.

on each component equal to the quantity level. The unit cost follows from the shadow price.

Preferably, the substitution elasticities (which are free parameters) should be based on empirical estimates. However, in the absence of such estimates we have to rely on judgement. At the first level, we assume that the elasticity is quite low ($\sigma = 0.5$). Thus, area, labour and livestock can only substitute for each other to a minor degree without reducing food security. On the second level, it is likely that substitution possibilities are higher, as it is of minor importance from what source (meat or milk) the proteins and the animal fat come. Here, we apply an elasticity of $\mu = 2$. It should be noted that between different meat products (beef, sheep, pig and poultry) we implicitly assume perfect substitutability.

4. Quantifying complementarities—model results

The model is calibrated to reproduce the actual situation in the base year 1998 as closely as possible, by including the actual support and tariff regime. In this year, total support amounted to 73 per cent of the value of agricultural production (OECD, 2003). Nearly half of the support was market price support, generated by high import tariffs. The rest of the support was payments based on output (15 per cent), area planted or animal numbers (12 per cent) and input use (25 per cent). The support was only to a minor degree targeted on provision of public goods, e.g. in terms of requirements for landscape preservation or the agricultural production systems.

Column 1 of Table 2 presents the base solution. In spite of climatic disadvantage, production is high (and imports low). Norway is self-sufficient in most products, and for dairy products there is even a surplus, which is dumped on the world market. The exception is grain. The arctic climate does not permit sufficient quantities of high-quality grain for bread-making. To sustain these high activity levels, substantial support is necessary (NOK 15.3 billion or €1.83 billion).[9] Because agriculture employs about 59,700 man-years, the support per man-year is about NOK 255,000 (€30,700).[10] The support rates are regressive with regard to farm size and favour agriculture in rural and less productive areas. Therefore, small-scale farming appears in most parts of Norway.

Column 2 gives the results of a simulation where landscape preservation is the only policy objective. Landscape preservation is implemented in the model as described in Section 3.2. The simulation assumes free trade and no subsidies, except those endogenously generated by the model to internalise the marginal willingness to pay for the amenity value of pasture and tilled land. Compared with the base solution, the activity in the agricultural sector is substantially reduced, especially production and employment (16 per cent of the

9 We have used the exchange rate €1 = NOK 8.30, which was the exchange rate that gave approximately purchasing power parity between Norway and EU in 1998.

10 Both total support and employment figures are somewhat lower than the actual ones. Support per man year, on the other hand, is approximately correct.

Table 2. Production and main input levels in Norwegian agriculture

	Base solution	Landscape preservation	Food security	Landscape preservation and food security
Production (million kg or litres)				
Milk	1671.5	139.1	832.1	709.6
Beef and veal	82.1	5.6	33.6	28.6
Pig meat	100.1	—	—	—
Sheep meat	23.0	28.0	18.4	29.7
Poultry meat	27.8	—	14.8	—
Eggs	43.8	—	16.7	9.8
Wheat	210.5	114.8	151.1	150.0
Coarse grains	1021.3	255.1	367.8	339.1
Potatoes	298.0	310.3	307.1	312.3
Land use (million hectares)	0.85	0.36	0.48	0.54
Tilled land	0.31	0.09	0.13	0.12
Grazing and pastures	0.54	0.27	0.35	0.42
Employment (1,000 man-years)	59.7	9.8	17.3	17.7
Economic surplus (NOK billion)	36.7	45.7	44.8	45.0
+ Consumer surplus	21.9	29.7	30.0	30.3
+ Value landscape	22.3	19.3	20.3	20.7
+ Producer surplus	1.1	—	—	—
− Budget support	8.6	3.3	5.5	6.0
Total support (NOK billion)	15.3	3.3	5.5	6.0
Border measures	6.7	—	—	—
Budget support	8.6	3.3	5.5	6.0
Landscape preservation	2.31	1	1.33	1.49
Food security	1.90	0.37	1	1

base solution level). Naturally, because land use enters into the WTP function, it declines less than the other indicators. Nevertheless, the computed level of land use is only 43 per cent of the present level. Land-intensive grazing, i.e. extensive sheep farming, holds up better than grain production on tilled land. Necessary support, in the form of area subsidies, is NOK 3.3 billion, or about one-fifth of the support in the base solution.

It should be noted that food security as well as private goods (food) follow as by-products of landscape preservation. More specifically, the index for food security is 37 per cent of the crisis menu level. This emphasises the joint-product nature of agricultural activity. The agricultural land that enters into production of landscape amenity values contributes also to food security.

In the next simulation, reported in column 3, we ignore landscape preservation and concentrate solely on food security. Here we include a constraint in the model saying that the level of food security has to be equal to or greater than unity ($FS \geq 1$). In other words, we require complete food security ($\lambda \geq 1$). No other regulations or support systems are imposed.

Naturally, the restriction is binding, which means that food security is not a free good. However, this level of food security can be provided at a considerably lower cost than is the case today. Agricultural support decreases to NOK 5.5 billion, or about one-third of the base solution. The support follows endogenously from the constraint on food security, and is thus targeted at the underlying factors of the food security production function, i.e. area, skilled labour and livestock. Employment and land use decline to 29 per cent and 56 per cent of the baseline levels. Compared with the landscape preservation scenario, however, activity levels are higher, especially production and employment, but also land use. This reflects the fact that food security requires a wider spectrum of inputs than landscape preservation. It should be noted that food security dominates landscape preservation, i.e. the level of landscape preservation that follows as a by-product of complete food security is higher than in the previous solution ($LP = 1.33$).

Looking more closely at the food security solution, we observe that it is optimal to have a product mix in normal times that differs from the requirements of the crisis menu. Grain production is reduced and is far below the levels required by the crisis menu. Relatively more of the area is applied to milk, meat and egg production. Also, for meat there has been a switch to land-intensive production techniques. Extensive production of sheep meat absorbs some of the land now used for grain production. If a crisis occurs, animal production will have to revert gradually to grain production while grain stocks are run down.

We now combine food security and landscape preservation. Thus, the WTP function for landscape preservation is added to the objective function while we keep the requirement that the level of food security must be equal to or exceed a floor of unity. Compared with the 'food security alone' solution, we see that adding willingness to pay for landscape preservation results in higher land use (+12 per cent), whereas employment is only slightly affected (+2 per cent). A further switch towards land-intensive techniques takes place, represented by the increase in extensive sheep meat production. The level of landscape preservation is 50 per cent higher than in the landscape preservation alone solution. This reflects the existence of complementarities between the two public goods: as a result of common inputs, support to obtain a desired level of food security also reduces the costs of keeping up the cultural landscape.

The above results are of course sensitive to the choice of parameter values in the various functions. A sensitive parameter is the degree of substitution between grazing and tilled land, σ. From the landscape preservation solutions we see that the proportion of grassland to tilled land is high compared with the base solution. This means that if we change σ from three to, for example, 0.5, activities using tilled land become relatively more attractive, and expand at the expense of grazing and pasture. This means that some outputs increase (potatoes and grain) whereas others decrease (sheep farming). Land use and employment also decrease. On the other hand, decreasing the elasticity, ε, in the willingness-to-pay function means a minor increase in land use and budget support. However, even if the parameter values are substantially changed the main qualitative conclusions still stand.

Cost functions for public goods are presented in Figures 4 and 5. Figure 4 shows net stand-alone costs (*NC*) of providing landscape preservation and food security, respectively, whereas Figure 5 gives incremental costs (*IC*) of increasing the supply of one public good (e.g food security) when the level of the other public goods (e.g. landscape preservation) is equal to or higher than unity.

At point A of Figure 4, $NC = 0$ for both public goods, which means that no support is given. In this case, almost no public goods are produced. This reflects the fact that Norwegian agriculture is unprofitable at world market prices. The points shown as B have *NC*s that correspond to a level equal to unity for each public good. These numbers are equal to the reported budget support in columns 2 and 3 of Table 2. Finally, the C points have *NC*s for the levels of public goods in the base solution. Not surprisingly, the levels of public goods achieved are high in the base solution. The index for landscape preservation is 131 per cent higher that the level reported in column 2, and the level of food security overshoots the needs derived from the crisis menu, reported in column 3, by 90 per cent. Also, the costs exceed the amounts in point B by about 160 per cent. Thus, it seems clear that the present high level of support can only to a minor degree be defended by the public good argument.

In Figure 5, the *IC* curves start to rise at $FS = 0.37$ and $LP = 1.33$, respectively. For each public good, this is the level that follows as a by-product, without extra cost, from one unit of the other public good. It can be seen that the *IC* of elevating the level of landscape preservation, when complete food security is assumed, is quite low. For example, only NOK 0.6 billion is required to raise the level of landscape preservation to the optimal level indicated in column 4 ($LP = 1.49$). This is because preservation of agricultural land is a major component of both landscape preservation and food security.

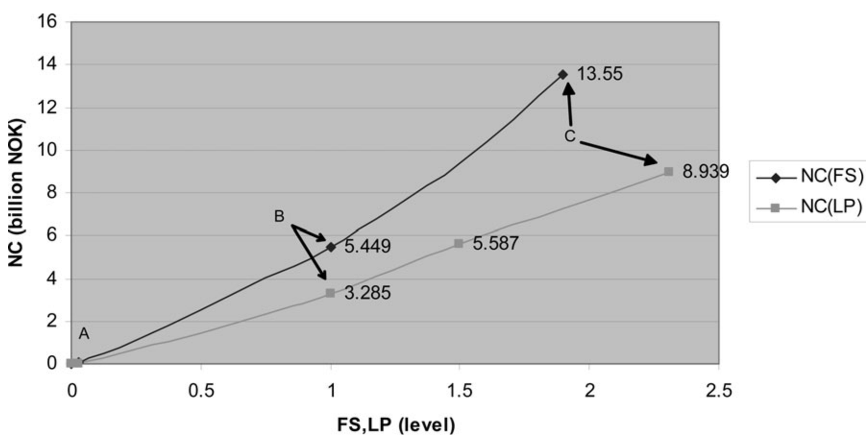

Figure 4. Net stand-alone costs (NC) of landscape preservation and food security.

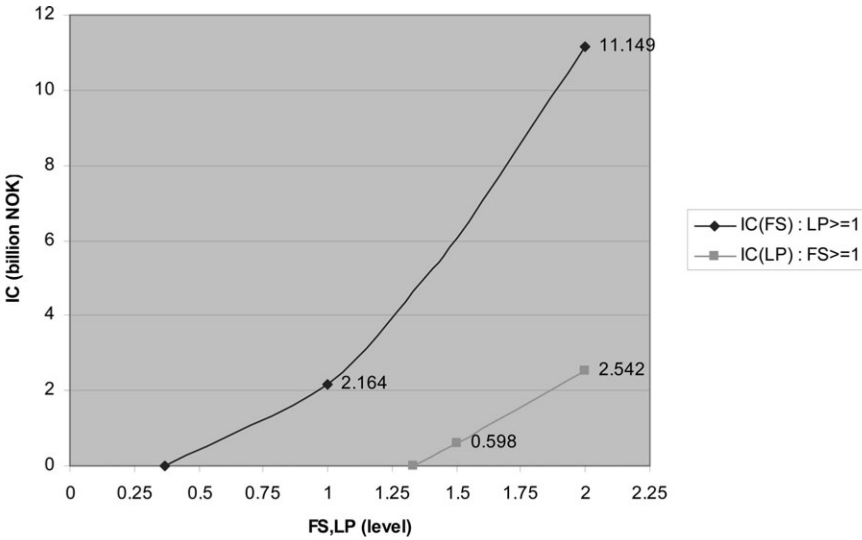

Figure 5. Incremental costs.

The *IC* is higher for food security, especially for high levels of food security ($\lambda > 1$), as food security requires more production and agricultural employment compared with the landscape preservation case.

Naturally, the low incremental costs for landscape preservation are due to strong cost complementarities, or economies of scope, between the public goods in question. An indicator of the degree of cost complementarities was presented in equation (9). Below, this indicator is evaluated for the optimal solution in column 4:

$$c = 100\frac{NC(L^M = 1) + NC(L^{LP} = 1.49) - NC(L^M = 1) - IC(L^{LP} = 1.49)}{NC(L^M = 1) + IC(L^{LP} = 1.49)}$$
$$= 100\frac{5.587 - 0.598}{5.449 + 0.598} = 82.5\%.$$

In this case the cost of joint production is $NC(L^M = 1) + IC(L^{LP} = 1.49)$, and the sum of stand-alone costs is $NC(L^M = 1) + NC(L^{LP} = 1.49)$. The corresponding values can be found in Figures 4 and 5.

As can be seen, the percentage extra costs of producing optimal levels of the two public goods separately, compared with joint production, are more than 80 per cent, which indicates that the cost complementarities are high.

5. Concluding remarks

Without support, the levels of agricultural public goods such as food security and landscape preservation will fall short of the demand in high-cost countries such as Norway, Finland, Iceland and Switzerland. However, as demonstrated in this paper using Norway as a case study, the current level of support is well out of proportion from a public goods perspective. Furthermore, the present support, stimulating high production levels, is badly targeted at the public goods in question. Because agricultural land is a major component of both food security and landscape preservation (as well as in the production of private goods), thus giving rise to a high degree of cost complementarity, it would be more efficient to support land-extensive production techniques than production *per se*. With optimal policy instruments, the simulations show that at most 40 per cent of the current support level can be defended by the public good argument. Naturally, production and trade will also be affected by support to sustain public goods, but, as illustrated by the simulations, to a far lesser extent.

Finally, it should be noted that our analysis only considers food security and landscape preservation. In principle, there may be other public goods that could affect the optimal policy, e.g. biodiversity, preservation of rural lifestyle or occupation of land for territorial defence.

Acknowledgement

Financial support from the Research Council of Norway, through the programme Living Conditions, Development and Restructuring of the Agriultural Sector, is gratefully acknowledged. An earlier version of this paper was presented at the 90th EAAE seminar, *Multifunctional agriculture, policies and markets: understanding the critical linkages*, Rennes, 27–29 October 2004.

References

Anderson, K. and Morris, P. (2000). The elusive goal of agricultural trade reform. *Cato Journal* 19: 385–396.

Ballenger, N. and Mabbs-Zeno, C. (1992). Treating food security and food aid issues at the GATT. *Food Policy* August: 264–276.

Beghin, J.C., Bureau, J. and Park, S.J. (2003). Food security and agricultural protection in South Korea. *American Journal of Agricultural Economics* 85: 618–632.

Boisvert, R.N. (2001). A note on the concept of jointness in production. *Multifunctionality: Towards an Analytical Framework*, Annex 1. Paris: OECD.

Brunstad, R.J. and Vårdal, E. (1989). Goal conflicts in the Norwegian farming industry: allocational loss through the pursuit of non-efficiency goals. In S. Bauer and W. Heinrichsmeyer (eds), *Agricultural Sector Modeling*. Kiel: Vauk, 97–101.

Brunstad, R.J., Gaasland, I. and Vårdal, E. (1995a). Agriculture as a provider of public goods: a case study for Norway. *Agricultural Economics* 13: 39–49.

Brunstad, R.J., Gaasland, I. and Vårdal, E. (1995b). A Model for the Agricultural Sector in Norway. Working Paper No. 25/95. Bergen: Foundation for Research in Economics and Business Administration (SNF).

Brunstad, R.J., Gaasland, I. and Vårdal, E. (1999). Agricultural production and the optimal level of landscape preservation. *Land Economics* 75: 538–546.

Davis, C.D., Thomas, C.Y. and Amponsah, W.A. (2001). Globalization and poverty: lessons from the theory and practice of food security. *American Journal of Agricultural Economics* 83: 714–721.

Drake, L. (1992). The non-market value of Swedish agricultural landscape. *European Review of Agricultural Economics* 19: 351–364.

Gaasland, I. (2003). En numerisk modell for analyse av norsk bioproduksjon og foredling. Rapport nr. 32/03. Bergen: Foundation for Research in Economics and Business Administration (SNF).

Gaasland, I., Mittenzwei, K., Nese, G. and Senhaji, A. (2001). Dokumentasjon av JORDMOD. Rapport nr. 17/01. Bergen: Foundation for Research in Economics and Business Administration (SNF).

Gulbrandsen, O. and Lindbeck, A. (1973). *The Economics of the Agricultural Sector*. Stockholm: Almquist and Wicksell.

Hediger, W. and Lehmann, B. (2003). Multifunctional agriculture and the preservation of environmental benefits. *Proceedings of the 25th Conference of the International Association of Agricultural Economists*. 16–22 August, 2003, Durban, South Africa, 1127–1135.

Lopez, R.A., Shah, F.A. and Altobello, M.A. (1994). Amenity benefits and the optimal allocation of land. *Land Economics* 70: 53–62.

NOU (1991). Norsk landbrukspolitikk. Utfordringer, mål og virkemidler. Oslo: Norges offentlige utredninger.

OECD (2001). *Multifunctionality: Towards an Analytical Framework*. Paris: Organisation for Economic Co-operation and Development.

OECD (2003). *Agricultural policies, markets and trade in OECD countries. Monitoring and evaluation 2003*. Paris: Organisation for Economic Co-operation and Development.

Peterson, J.M., Boisvert, R.N. and de Gorter, H. (2002). Environmental policies for a multi-functional agricultural sector in open economies. *European Review of Agricultural Economics* 29: 423–443.

Sumner, D.A. (2000). Agricultural trade policy and food security. *Quarterly Journal of International Agriculture* 39: 395–409.

Winters, L.A. (1989–1990). The so-called 'non-economic' objectives of agricultural support. OECD Economic Studies 13. Paris: Organisation for Economic Cooperation and Development, 237–266.

Appendix

The model is a partial equilibrium model of the Norwegian agricultural sector. For given input costs and demand functions, market clearing prices and quantities are computed. Prices of goods produced outside the agricultural sector or abroad are taken as given. As the model assumes full mobility of labour and capital, it must be interpreted as a long-run model. A technical description of an earlier version of the model is given in Brunstad *et al*. (1995b).

The model covers the most important products produced by the Norwegian agricultural sector, in all 14 final and nine intermediary products. Most products in the model are aggregates. Primary inputs in the model are land (four different grades), labour (family members and hired), capital (machinery, buildings, livestock) and other inputs (fertilisers, fuel, seeds, etc.). The prices of inputs are determined outside the model and treated as given.

Supply in the model is domestic production plus imports. Domestic production takes place on the model's approximately 400 different 'model farms'. The farms are modelled with fixed input and output coefficients, based on data from extensive farm surveys carried out by the Norwegian Agricultural Economics Research Institute, a research body connected to the Norwegian Ministry of Agriculture. Imports take place at given world market prices inclusive of tariffs and transport costs. Domestic and foreign products are assumed to be perfect substitutes. The country is divided into nine production regions, each with limited supply of the different grades of land. This regional division allows for regional variation in climatic and topographic conditions and makes it possible to specify regional goals and policy instruments. The products from the model farms go through processing plants before they are offered on the market. The processing plants are partly modelled as pure cost mark-ups (meat, eggs and fruit), and partly as production processes of the same type as the model farms (milk and grains).

The domestic demand for final products is represented by linear demand functions. These demand functions are parameterised using demand elasticities from existing studies, and are linearised to go through the observed price and quantity combination in the base year (1998). Between the meat products there are cross-price effects, whereas cross-price effects are neglected for all other products for which the model assumes only own-price effects. The demands for intermediate products are derived from the demands for the final products for which they are inputs. Exports take place at given world market prices.

Domestic demand for final products is divided among five separate demand regions, which have their own demand functions. Each demand region consists of one or several production regions. If products are transported from one region to another, transport costs are incurred. For imports and exports, transport costs are incurred from the port of entry and to the port of shipment respectively. In principle, restrictions can be placed on all variables in the model. The restrictions that we include can be divided into two groups:

(i) Scarcity restrictions: upper limits for the endowment of land, for each grade of land in each region.
(ii) Political restrictions: lower limits for land use and employment in each region, for groups of regions (central regions and remote areas), or for the country as a whole; maximum or minimum quantities for domestic production, imports or exports; maximum prices.

In the model, the economic surplus (consumer surplus plus producer surplus) of the agricultural sector is maximised, subject to demand and supply relationships and the imposed restrictions. Which restrictions are included depends upon what kind of simulation is attempted. The solution to the model is found as the prices and quantities that give equilibrium in each market. No restrictions should be violated, and no model farm or processing plant that is active should be run at a loss.

Corresponding author: Erling Vårdal, Department of Economics, University of Bergen, Herman Fossgate 6, 5007 Bergen, Norway. Telephone: (47) 55 58 92 00. Fax: (47) 55 58 92 10. E-mail: erling.vardal@econ.uib.no