Meeting multiple policy objectives under GHG emission reduction targets[1]

Richard N. Boisvert, Cornell University, Ithaca, NY, USA

David Blandford, The Pennsylvania State University, University Park, PA, USA

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Despite limited progress, efforts continue to reach agreement on binding global commitments for reductions in greenhouse gas (GHG) emissions through the United Nations Framework Convention on Climate Change. Any future agreement will likely involve the agricultural sector, which heretofore has been exempted from most national emission reduction initiatives.

Although agriculture accounts for less than 1% of Norway's gross domestic product it is estimated to account for roughly 8% of GHG emissions. Norwegian agriculture is also one of the most heavily protected in the world. The OECD's producer support estimate (PSE) for Norway of 60% in 2010 was the highest among the member countries of the Organization (OECD, 2011). Like many other countries, Norway pursues a range of objectives for its agricultural sector. The traditional emphasis has been on productivity, food security and providing income and employment. More recently, landscape preservation and improving environmental quality have become increasingly important (Lyssandtræ, 2006). If there is a need to reduce GHG emissions from Norwegian agriculture, this may have to be balanced against other objectives. Future policies for the sector will have to address multiple and sometimes conflicting outcomes.

In this paper we examine this problem through a theoretical model of an agricultural sector that supplies a positive environmental attribute (landscape amenity) as well as two negative attributes (GHG emissions and nutrient contamination of ground and surface water). The sector can also engage in production activities that contribute to reductions in the concentration of carbon in the atmosphere (carbon sequestration activities). In our model this involves devoting agricultural land to growing trees (agro-forestry). We use the model to examine policy choices designed to increase the positive domestic environmental contribution of agriculture, while at the same time reducing its negative contribution. We also use the model to examine the implications for achieving domestic environmental objectives of the imposition of an internationally determined GHG emission reduction requirement on agriculture. Our focus is solely on the achievement of environmental objectives and we do not include any other objectives, such as a redistribution of income from consumers to farmers. In the final section we address some complications and implications that our theoretical results have for programme design and implementation. While the theoretical model encompasses some essential features to examine the policy choices for multiple environmental objectives in Norway, we believe the analytical results, as well as the implications for programme design and implementation have more general applicability both in Europe and elsewhere.

The Model

Our model of agricultural production contains the essential components for analysing the situation in which agricultural producers adjust to domestic policies designed to promote national environmental objectives. We then examine the incorporation of the internationally determined environmental

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objective. In the model, aggregate agricultural output, Y, depends on three inputs, land and two input bundles composed of differing aggregates of other factors of production. The well-behaved production function is given by:

(1) $Y = Y(L_y, K_y, K_a)$,

where L_y and K_y are inputs of land and other inputs, respectively, used to produce agricultural goods, and, as discussed below, K_a are inputs used in the production of landscape amenities. These inputs are different from those used solely to produce agricultural output, but are assumed to affect the level of that output. In what follows we shall refer to the category K as non-land inputs, whose composition is allowed to differ in the production of commodity and non-commodity outputs.

In addition to generating agricultural commodities, land that is committed to agricultural production is assumed to generate environmental public goods (e.g. landscape amenities). These are produced according to:

(2) $A = A(L_y, K_a, K_y)$.

The aggregate of other inputs, K_a, is also included as an argument in the production function for landscape because amenity value (often referred to as the "cultural landscape") depends on how land is managed[3] and cultural landscape is assumed to improve with the intensity of management, as measured by K_a/L_y.[4] Thus, the composition of the non-land input bundle K_a that is specifically oriented to the production of amenities, will likely differ (e.g., the mix of labor, capital and purchased inputs) from that devoted to agricultural production, K_y. However, K_y is also assumed to affect the production of landscape amenities, either negatively or positively. As agricultural production becomes more non-land-input intensive, *ceteris paribus*, the quality of landscape amenities may well decline, but there could be cases in which the reverse might apply.[5]

The production of agricultural commodities also generates two forms of pollution: GHG emissions and nutrient contamination of ground and surface water. These respective pollutants are produced according to the functions:

(3) $G = G(L_y, K_y)$, and

[3] Existing studies suggest that there are several attributes that enhance the value of the landscape such as biodiversity, variation, grazing animals, openness and environmental benefits, and that cultural landscape is a spatial public/externality good (e.g., Drake, 1992 and Dillman and Bergstrom, 1991).

[4] This formulation does not imply that landscape amenities are produced in fixed proportions with agricultural output or even land committed to agricultural production. Farmers can increase or decrease the amenity value of land in agriculture independently from the volume of agricultural output. For example, the amenity function may be similar to the semi-logarithmic function used by Chang *et al*. (2005) to model a similar non-commodity output from agriculture. If we let $A = \lambda \log\left\{K_a^{\alpha}(\beta L_y)^{(1-\alpha)}\right\}$, where a given level of Ky is assumed to be included in the constant term λ. The expression in { } can be rewritten as $\left\{\left(\frac{K_a}{\beta L_y}\right)^{\alpha}(\beta L_y)\right\}$.This highlights the fact that the intensity of application of non-land inputs per unit of land area affects landscape amenities, as does the increase in the overall amount of land in agriculture. This latter assumption implies that production of landscape is not proportional to agricultural output although there is a linkage between agricultural activity and the supply of amenities by virtue of the land allocated to agricultural production.

[5]It is important to note that in our model, both agricultural production and landscape depend on both K_a and K_y, and that the relationships can be positive or negative. It could well be the case, for example, that the collection of machinery and buildings, odour, manure disposal facilities, etc. related to large scale animal agriculture will diminish the value of the nearby landscape. Alternatively, attractive fields made possible by the application of nutrients to certain crops may add to the quality of the cultural landscape. Similarly some of the investment in maintaining field boundaries designed to enhance the landscape may provide a better habitat for honey bees and add to agricultural crop output through more effective pollination.

(3′) $N = N(L_y, K_y)$.

The production of these two forms of pollution depends on the land committed to agricultural production and the application of the particular non-land inputs that contribute to agricultural output.[6]

We also assume that farmers can devote land and an aggregate bundle of non-land inputs to agro-forestry rather than to the production of agricultural output. The well-behaved forestry production function is:

(4) $F = F(L_f, K_f)$.

As in the other functions above, the composition of the non-land bundle of inputs can differ from that used in the production of agricultural commodities or landscape amenities. Agro-forestry will generate woody biomass that can be sold in the market (for timber, fuel wood, etc.). In addition, land committed to forestry also serves to sequester carbon, according to the function:

(5) $S = S\left(F(L_f, K_f)\right)$.

While the level of carbon sequestration is a function of the level of forestry production (land in forestry), it is also assumed to be affected by the type of forestry (e.g., short- versus long-rotation, use of tree species with differing growth patterns), which, for our purposes, could also be reflected in the non-land input intensity of production, K_f/L_f.[7]

Classification of Inputs and Joint Production

Before proceeding, it is important for the policy discussion to understand how the two market goods (agricultural output and agro-forestry output) must each be viewed as being produced jointly along with their respective non-commodity outputs. The products can be linked in joint production through short-term constraints on *allocable* inputs and/or the existence of *non-allocable* factors of production (Beattie *et al*., 2009 and Peterson *et al*., 2002). An input is said to be *non-allocable* if one cannot distinguish between the units of the factor being used to produce one of the outputs from those being used in the production of any other (Beattie *et al*., 2009).

For the purposes of understanding resource allocation decisions by farmers in response to agro-environmental policy, it is critical to recognize that land committed to the simultaneous and joint production of agricultural output, GHG emissions, nutrient pollution, and landscape amenities falls into the category *of a non-allocable* input. And, as is often the case in agriculture, some of the joint outputs are traded in organized markets, while others have public good attributes or are environmental externalities that are not traded in organized markets.

Similar to land, the non-land composite input bundle, K_y, is *non-allocable* in the production of agricultural output, GHG emissions, and nutrient pollution. In contrast, the use of the non-land composite input bundle K_a is allocable between the production of landscape amenities and the other three joint outputs from agricultural production (i.e. K_y is distinct from K_a). Agro-forestry and the sequestration of carbon are also joint products because the inputs used for these are non-allocable between the two products.

[6] We exclude the use of specific input bundles designed to reduce negative externalities in this formulation, but note the implications of a more complex specification later in the paper.

[7] We assume that agro-forestry has a neutral effect on ground and surface water quality. Forestry can actually have a positive effect on the quantity and quality of water resources.

To complete the description of the model, we assume there are fixed market prices for agricultural and agro-forestry outputs of P_y and P_f, respectively.[8] Furthermore, there is a fixed quantity of land, $L^* = L_y + L_f$.[9] In contrast, the supplies of the distinct composite non-land inputs, (K_y, K_a, and K_f) are unconstrained and their market prices (P_{ky}, P_{ka} , and P_{kf}) are also assumed to be exogenous. Finally, in order to examine the producer's resource allocation decisions, we assume that the marginal social values of GHG emissions, carbon sequestration, nutrient pollution, and landscape amenities are reflected through a set of fixed prices denoted by P_g, P_s, P_n, and P_a respectively.[10]

The Producer's Problem

Given these parameters, the producer's problem is to maximize profit (revenue minus costs), subject to the fixed prices for all relevant outputs and the land constraint:

(6) $$+P_f F(L_f, K_f) + P_g G(L_y, K_y) + P_n N(L_y, K_y) + P_a A(L_y, K_a, K_y) + P_s S\left(F(L_f, K_f)\right) - \left(P_{ky}K_y + P_{ka}K_a + P_{kf}K_f\right) + \mu\left[L^* - L_y - L_f\right].$$

Assuming an interior solution, the first-order necessary conditions for a maximum are given by:

(7) $P_y Y_{Ly} + P_g G_{Ly} + P_n N_{Ly} + P_a A_{Ly} - \mu = 0,$

(8) $P_y Y_{Ky} + P_a A_{Ky} + P_g G_{Ky} + P_n N_{Ky} - P_{ky} = 0,$

(8a) $P_a A_{Ka} + P_y Y_{Ka} - P_{ka} = 0,$

(9) $P_f F_{Lf} + P_s S' F_{Lf} - \mu = 0,$

(10) $P_f F_{Kf} + P_s S' F_{Kf} - P_{kf} = 0$, and

(6a) $L^* - L_y - L_f = 0.$

The subscripts on the terms Y, F, G, A, N, and S are used to denote partial derivatives. The first-order conditions underscore the effects of non-allocable inputs for jointly-produced goods on optimal input use when farmers account for the social value of public/externality outputs in their production decisions. The optimal level of each non-allocable input in the production of agricultural output occurs where the shadow price or market price of that input equals the sum of the marginal value products of the respective inputs in the production of the agricultural commodity and public/externality goods (e.g. GHG emissions, nutrient pollution, and landscape amenities) jointly produced. Similarly, the optimal level of each non-allocable input in the production of the agro-forestry output occurs where the shadow price or market price of that input equals the sum of the marginal value products of the respective inputs in the production of the agro-forestry commodity and the public/externality good (e.g. carbon sequestration) that is jointly produced.

[8] We subsequently relax the assumption that the price of agricultural output is fixed.

[9] By introducing this land constraint into the model, there is yet another condition for jointness in production: a fixed availability of an *allocable* input. Both forestry and agricultural production compete for the fixed amount of land available, which is an (*allocable*) input between the two sets of production activities. With this land constraint, however, the joint nature of production is reflected by the fact that as more land is allocated to forestry there must be a reduction both in land allocated to agricultural production, and in agricultural output (Boisvert, 2001). This cause of joint production would not exist if additional land could be purchased at a fixed price or if prices were determined in a competitive land market.

[10] These may be interpreted as a set of policy-determined subsidies/taxes for the environmental goods/bads that are known to producers.

In principle, as indicated above, the fact that the allocation of inputs in agricultural production is unaffected by the productivity of inputs in agro-forestry production [compare equations (7, 8, and 8a) with equations (9 and 10)] reflects the fact that the two inputs are allocable between these two sets of joint products. This would indeed be the case if farmers could buy land in the market, and there were no constraint on the amount purchased. However, the jointness in production due to the fixed input of land is reflected in the land constraint, equation (6a), and it is this constraint, along with the Lagrangian multiplier, μ, in equation (7) and (9), that links the remaining five equations and ultimately determines input allocation.

If agricultural producers face zero social prices for the jointly produced public/externality outputs (e.g. P_g, P_s, P_n, and $P_a = 0$), then the social values of these products will not affect input allocation decisions. This is the competitive market solution, and input use will not be socially optimal. To help understand how the social values of these non-market externalities affect input use, we can examine each of the first-order conditions individually.[11]

It is perhaps easiest to begin with equation (9). To do so we must first make reasonable assumptions about the nature of the functions F and S. We assume that the marginal product (MP) of land in the production of forestry output is positive, but declining, and the marginal product of forestry in carbon sequestration is also positive, but also declining.

Based on these assumptions, and the fact that $P_f > 0$, and $P_s > 0$ (e.g. carbon sequestration has a positive social value), the optimal amount of land committed to forestry will tend to be higher than under competitive market conditions in which there is no explicit recognition of the social value of this positive non-commodity externality. The marginal social value of sequestration essentially drives a wedge between the shadow price of land and the marginal value of its use in forestry. Since μ can be assumed to be positive, and for any level of L_f, the value of the left-hand side of equation (9) is higher than it would be without accounting for the social value of sequestration. Thus, if both F and S are well-behaved, and the MP schedules of land are declining, more agricultural land must be committed to forestry production, relative to that for the competitive equilibrium, to reduce its marginal productivity and re-establish equilibrium.

A similar line of reasoning applied to equation (10) would lead to a similar conclusion. The optimal use of input K_f committed to forestry will tend to be higher than under competitive market conditions in which there is no explicit recognition of the social value of carbon sequestration.

The situation in equation (7) is more complex since landscape amenities are affected by the allocation of land to agricultural production, as are GHG emissions and nutrient pollution. Thus, the effect of explicit recognition of the social values of these three non-market commodities on the optimal allocation of land in agriculture relative to that in the competitive market case depends on the marginal contribution of land to *net* social value. If the combined negative marginal contribution to social welfare due to production of GHG emissions and nutrient pollution is larger in absolute value than the positive marginal contribution to social welfare due to the provision of landscape amenities (e.g. $P_g G_{Ly} + P_n N_{Ly} + P_a A_{Ly} < 0$), one must reduce the use of land in agriculture in order to raise its marginal product and re-establish equilibrium. The reverse is the case if the net marginal contribution of the three non-market goods to social welfare is positive (e.g. $P_g G_{K=Ly} + P_n N_{Ly} + P_a A_{Ly} > 0$).

The examination of equation (8) is similar, but now two of the non-commodity outputs (GHG emissions and nutrient pollution) whose production levels are affected by K_y have negative social values (e.g. $P_g < 0$ and $P_n < 0$), while landscape amenities, also affected by K_y, have positive social value, $P_a > 0$. It is reasonable to assume that K_y's marginal products in the production of agricultural output, GHG emissions, and nutrient pollution are positive, but declining. Therefore, the marginal

[11] While we gain important insights into the effects of these social values on the allocation of productive inputs through this approach, the final effects on input use and the production of the various outputs can only be determined through the simultaneous solution of this system of equations, including the land constraint.

values of emissions and nutrient pollution drive a wedge between the price of the input and the marginal value of the agricultural output. Since $P_{ky} > 0$, but $P_g < 0$ and $P_n < 0$. Under these conditions, the terms $P_g G_{Ky} + P_n N_{Ky}$ would both be negative and the value of the left-hand side of equation (8) would be lower than in the absence of accounting for the social cost of GHG emissions and nutrient pollution. Furthermore, if the marginal contribution of K_y to amenities is negative, the term $P_a A_{Ky}$would also be negative, and to re-establish equilibrium one would have to reduce the use of input K_y, again relative to that under the competitive equilibrium, in order to raise its marginal product and restore equilibrium.[12]

Similarly, the allocation of K_a to the production of landscape amenities affects the level of agricultural production. Thus, an examination of equation (8a) reveals that the optimal allocation of the input K_a^* is where the value of the marginal product of K_a in producing landscape amenities (whose social value, $P_a > 0$) plus the value marginal product of K_a in producing agricultural output equals the price, P_{ka}. To the extent that the application of non-land inputs to the production of landscape amenities reduces agricultural production, there would be a tendency for the level of K_a to be lower than in the competitive situation where farmers do not account for the social value of landscape. Under these conditions, there would be no incentive for farmers to allocate any of the variable input K_a to improve the quality of landscape. If, however, the marginal product of K_a in agriculture is positive, the level of K_a would be above that under competition, and even if farmers do not account for the social value of landscape, some "amenity-specific" non-land inputs would be applied in agricultural production.

The Policy Framework

Conceptually, a government could achieve efficiency in the production of both private goods and the public/externality goods in two ways: 1) by taxing or subsidizing them at their social values, or 2) by direct regulation of the quantities of these externalities at their socially optimal levels through a set of command and control policies. The former of these two approaches is reflected in the model above. The first strategy is the well-known Pigouvian solution (Spulber, 1985), and, as demonstrated, its properties can be identified theoretically through an indirect profit function that depends on the prices of all outputs. Unfortunately, the implementation of such a policy approach is unlikely to be much help in practice. As Peterson *et al*. (2002) indicate, the difficulty in the case of agriculture is that landscape amenities, GHG emissions and nutrient pollution are almost always unobservable, not measurable in a traditional way, or measurable only at substantial cost. Thus, they can neither be priced nor regulated directly. In this case, practical policies will need to focus on observable outputs and inputs.

In what follows, we build on previous results from the trade and environmental economics literature. For the case of joint production in commodity and non-commodity outputs, we derive a policy scheme to internalize simultaneously the social benefits and costs of positive and negative externalities through taxes/subsidies on inputs.[13] We develop a set of optimal taxes and subsidies on productive inputs which yields results equivalent to the Pigouvian solution in which externalities are taxed or subsidized at their social values assigned *at the national level*. We go on to contrast this policy solution with one in which a GHG emissions reduction target (i.e. a constraint on the allowable level of GHG emissions) is *imposed by an international agreement*, which allows for the possibility that the target may not be consistent with national environmental policy goals.

[12] In the event that the marginal contribution of K_y to amenities is positive, the term $P_a A_{Ky}$would also be positive, partially or totally reversing the reduction in the use of K_y due to the negative marginal social values of GHG emissions and nutrient pollution.

[13] As suggested by Peterson *et al*. (2002) and Chang *et al*. (2005), these results extend the results by Holtermann (1976) and Stevens (1988) who derive optimal input taxes for a single externality.

The Welfare Maximization Problem

Social welfare can be represented as the sum of consumer and producer surplus.[14] To maximize domestic social welfare, we must solve the following maximization problem, where the decision variables are the levels of land and/or non-land inputs used in agricultural production (L_y and K_y), in forest production (L_y and K_y), and in generating landscape amenities (K_a):

$$(11) max \int_{P_y(Ly,Ky)}^{\infty} x(\widetilde{P_y})d\tilde{P}_y + P_y(L_y,K_y)Y(L_y,K_y,K_a) + P_f F(L_f,K_f) - D_g[G(L_y,K_y)]$$
$$- D_n[N(L_y,K_y)] + B_a[A(L_y,K_a,K_y)] + B_s\left[S\left(F(L_f,K_f)\right)\right]$$
$$- [(P_{ky}K_y + P_{ka}K_a + P_{kf}K_f)] + \mu[L^* - L_y - L_f]$$

where $x(\widetilde{P_y})$ is the domestic demand function for the agricultural output, $D_g(\cdot)$ is the domestic social damage function for GHG emissions, $D_n(\cdot)$ is the domestic social damage function for nutrient pollution, $B_a(\cdot)$ is the domestic social benefit function for landscape amenities, and $B_s(\cdot)$ is the domestic social benefit function for carbon sequestration.[15] We assume that the marginal contribution of each argument in the benefit and cost functions is positive but declining. We also assume that agricultural producers are price takers in the forest products market and face an exogenous price of P_f, but that this is not necessarily the case for agriculture (i.e., we relax the assumption of a fixed price for agricultural output made earlier). Following Peterson *et al*. (2002), we can write the equilibrium price of agricultural output as being determined by the equation:

$$(12) \quad Y = x(P_y) + x^*(P_y)$$

where $x^*(P_y)$ is the net foreign demand function, which is positive, negative or zero, respectively, for net exporters, net importers, or countries with no trade.[16]

The decision variables in this problem are again the levels of land and/or non-land inputs used in agricultural production (L_y and K_y), in forest production (L_y and K_y), and in generating landscape amenities (K_a). The first-order necessary conditions for a maximum are:

$$(13) \quad -x(P_y)\frac{\partial P_y}{\partial L_y} + \frac{\partial P_y}{\partial L_y}Y(\cdot) + P_y Y_{Ly} - D_g'(\cdot)G_{Ly} - D_n'(\cdot)N_{Ly} + B_a'(\cdot)A_{Ly} - \mu = 0,$$

$$(14) \quad -x(P_y)\frac{\partial P_y}{\partial K_y} + \frac{\partial P_y}{\partial k_y}Y(\cdot) + P_y Y_{Ky} - D_g'(\cdot)G_{Ky} - D_n'(\cdot)N_{Ky} + B_a'(\cdot)A_{Ky} - P_{ky} = 0,$$

$$(14a) \quad B_a'(\cdot)A_{Ka} + P_y Y_{Ka} - P_{ka} = 0,$$

[14] Casmatta *et al*. (2011) examine optimal policy choice given joint production of agricultural goods and rural amenities where policymakers place differential weights on the welfare of producers and consumers. The preferential treatment of farmers' welfare in many developed countries, including Norway, is not examined in this paper.

[15] By design, we assume that the domestic social benefit function for carbon sequestration is not equal to the negative of the domestic social damage function for GHG. This reflects the fact that growing forests capture carbon at different rates over time. Furthermore, forests may be used as biomass fuel. There is growing evidence that such fuels are not carbon neutral, contrary to a view generally held by many who promote their use. Since the 1990's, research suggests that the atmospheric greenhouse gas implications of burning forest biomass for energy vary depending on the characteristics of the bioenergy combustion technology, the fossil fuel technology it replaces, and the biophysical and forest management characteristics of the forests from which the biomass is harvested (Walker *et al*., 2010 and Rose and McCarl, 2010).

[16] The last case can apply to countries that protect their domestic agriculture from international competition through high tariffs or other trade restrictive measures.

(15) $P_f F_{Lf} + B_s'(\cdot)S'F_{Lf} - \mu = 0,$

(16) $P_f F_{Kf} + B_s'(\cdot)S'F_{Kf} - P_{Kf} = 0$, and

(11a) $L^* - L_y - L_f = 0.$

Solving for $x^*(P_y)$ in equation (12), substituting the result into equations (13) and (14), and rearranging, equations (13) through (16) become:

(13′) $x^*(P_y)\frac{\partial P_y}{\partial L_y} + P_y Y_{Ly} - D_g'(\cdot)G_{Ly} - D_n'(\cdot)N_{Ly} + B_a'(\cdot)A_{Ly} = \mu,$

(14′) $x^*(P_y)\frac{\partial P_y}{\partial K_y} + P_y Y_{Ky} - D_g'(\cdot)G_{Ky} - D_n'(\cdot)N_{Ky} + B_a'(\cdot)A_{Ky} = P_{ky},$

(14a′) $B_a'(\cdot)A_{Ka} + P_y Y_{Ka} = P_{ka},$

(15′) $P_f F_{Lf} + B_s'(\cdot)S'F_{Lf} = \mu,$ and

(16′) $P_f F_{Kf} + B_s'(\cdot)S'F_{Kf} = P_{Kf}.$

For large countries, the first terms in equation (13′) and (14′) are terms of trade effects due to the change in the value of imports/exports resulting from changes in domestic prices, and are analogous to optimal tariffs/export taxes (Peterson *et al*., 2002); these terms are zero for small countries facing exogenous world prices. The remaining terms on the left-hand side of all five equations are the marginal social benefits from producing each of the joint outputs. Each of these conditions requires the marginal social benefits of an input to equal its marginal social costs.

Optimal Policies for a Small Economy—Input Taxes and Subsidies

Let us first consider a small economy with a set of taxes and subsidies on *L* and *K*, which are distinct for each land use and non-land input bundle used in the production of agricultural output, to improve the cultural landscape, and increase carbon sequestration from agroforestry:

(17) $\max_{L_y,K_y,L_f,K_f} P_y Y(L_y, K_y, K_a) + P_f F(L_f, K_f) - (P_{Ky} + t_{Ky})(K_y) - (P_{Kf} + t_{Kf})(K_f) - (P_{Ka} + t_{Ka})(K_a) + s_{Ly}(L_y) + s_{Lf}(L_f) + (\mu)[L^* - L_y - L_f],$

where P_y and P_f are the exogenous prices of agricultural and agro-forestry outputs, respectively; P_K is the price of the associated input bundle *K*., and μ is the shadow price of land. Furthermore, s_{Ly}, and s_{Lf} are subsidies for land committed to agricultural and forestry production, respectively. Finally, t_{Ky}, t_{Kf}, and t_{Ka}, are the respective taxes on non-land inputs committed to: agricultural production (along with the production of GHG and water pollution); forestry production (along with carbon sequestration); and landscape amenities.[17]

Assuming an interior solution, the first-order necessary conditions for a maximum are given by:

(18) $P_y Y_{Ly} = \mu - s_{Ly},$

[17] Since these inputs are allocable between the two sets of joint products, there is a need to be able to tax or subsidize their use differentially. This is consistent with Tinbergen's old, but well known principle that policy optimality requires at least as many policy instruments as there are objectives. If we are to achieve optimal social welfare through taxes or subsidies on inputs used to produce different joint products, we need one instrument for each input for each product.

(19) $P_y Y_{Ky} = P_{ky} + t_{Ky}$,

(19a) $-P_{Ka} - t_{Ka} = 0$,

(20) $P_f F_{Lf} = \mu - s_{Lf}$,

(21) $P_f F_{Kf} = P_{kf} + t_{Kf}$, and

(17a) $L^* - L_y - L_f = 0$.

To maximize social welfare, we require that the taxes and subsidies on inputs be consistent with equations (13′) through (16′). That is accomplished by substituting equations (13′) through (16′) into equations (18) through (21). Recalling that there are no terms of trade effects for this small country, we have:

(22) $P_y Y_{Ly} = P_y Y_{Ly} - D_g'(\cdot) G_{Ly} - D_n'(\cdot) N_{Ly} + B_a'(\cdot) A_{Ly} - s_{Ly}$,

(23) $P_y Y_{Ky} = P_y Y_{Ky} - D_g'(\cdot) G_{Ky} - D_n'(\cdot) N_{Ky} + B_a'(\cdot) A_{Ky} + t_{Ky}$,

(23a) $B_a'(\cdot) A_{Ka} + P_y Y_{Ka} = -t_{Ka}$,

(24) $P_f F_{Lf} = P_f F_{Lf} + B_s'(\cdot) S' F_{Lf} - s_{Lf}$, and

(25) $P_f F_{Kf} = P_f F_{Kf} + B_s'(\cdot) S' F_{Kf} + t_{Kf}$.

After some rearranging, we have:

(22′) $s_{Ly} = B_a'(\cdot) A_{Ly} - D_g'(\cdot) G_{Ly} - D_n'(\cdot) N_{Ly}$,

(23′) $t_{Ky} = D_g'(\cdot) G_{Ky} + D_n'(\cdot) N_{Ky} + B_a'(\cdot) A_{Ky}$,

(23a′) $t_{Ka} = -B_a'(\cdot) A_{Ka} - P_y Y_{Ka}$,

(24′) $s_{Lf} = B_s'(\cdot) S' F_{Lf}$, and

(25′) $t_{Kf} = -B_s'(\cdot) S' F_{Kf}$.

It is evident from equations (22′) through (25′) that these input policies are a straightforward generalization of previous results in the literature for a single externality. Each input is rewarded by the net marginal value of its contribution to the several externalities.

This implies, for example, that land committed to forestry will be subsidized at s_{Lf} because of its marginal contribution to carbon sequestration. Similar reasoning suggests that t_{Kf} will also be negative because the application of additional *K* to forestry also contributes to social welfare through the associated increase in carbon sequestration. In the event that the marginal contribution of K_a to agricultural production is positive, additions to the private value of agricultural output also add to the social benefits of improvements in landscape amenities and t_{Ka} will be unambiguously negative (a subsidy).[18] On the other hand, the amount of the subsidy due to enhanced social value of landscape would be reduced, or could be eliminated completely, if K_a's marginal contribution to agricultural

[18] As noted earlier, we have not allowed for the use of input bundles in the functions 3 and 3′ that reduce GHG emissions and nutrient pollution. If such bundles exist, following the logic used here, it would be optimal to subsidize their use in order to enhance domestic social welfare.

output is negative. From equation (23′), we know that the tax on K applied to agricultural production, t_{Ky}, will likely be positive because its use contributes to both reduced GHG emissions and nutrient contamination, and these effects can be quite large. In the event that these particular non-land inputs at the margin diminish the cultural landscape, the tax would be larger still, but it could be partially offset if these agricultural-specific non-land inputs at the margin serve to enhance the cultural landscape.

Since land committed to agricultural production affects landscape amenities while at the same time contributing to GHG emissions and nutrient pollution, the sign of s_{Ly} is also ambiguous.
Only if the marginal social benefit of land in the production of landscape amenities is larger than the combined marginal social damage from GHG emissions and nutrient pollution will land be subsidized. If the reverse is true, there will be a tax on land in agricultural production.

Command and Control Regulation of GHG Emissions

While this model accounts for the national social value of the reductions in GHG emissions, any future agreement by the global community is likely to come in the form of country quotas for reductions in GHG emissions. Accordingly, the policy challenge for individual countries will be to maximize domestic social welfare, given the required emissions reduction, along with implementing policies to deal with national environmental objectives related to agriculture.

In this event, domestic social welfare must now be maximized subject to an additional condition, the GHG constraint, where GHG emissions can exceed the upper limit only to the extent that excess emissions are offset by a discounted amount of carbon sequestration, $0 < \theta < 1$, through forest production. The constraint can be written as:

$$G(L_y, K_y) + \theta S\left(F(L_f, K_f)\right) = GHG^*.$$

The welfare maximization problem now becomes:

$$(26) max \int_{P_y(Ly,Ky)}^{\infty} x(\widetilde{P_y})d\tilde{P}_y + P_y(L_y, K_y)Y(L_y, K_y, K_a) + P_f F(L_f, K_f) - D_g[G(L_y, K_y)]$$
$$- D_n[N(L_y, K_y)] + B_a[A(L_y, K_a, K_y)] + B_s\left[S\left(F(L_f, K_f)\right)\right]$$
$$- [(P_{ky}K_y + P_{ka}K_a + P_{kf}K_f)] + \mu[L^* - L_y - L_f]$$
$$+ \gamma\left[GHG^* - G(L_y, K_y) + \theta S\left(F(L_f, K_f)\right)\right]$$

The first-order necessary conditions for a maximum are given by:

$$(27)\ -x(P_y)\frac{\partial P_y}{\partial L_y} + \frac{\partial P_y}{\partial L_y}Y(\cdot) + P_y Y_{Ly} - D_g'(\cdot)G_{Ly} - D_n'(\cdot)N_{Ly} + B_a'(\cdot)A_{Ly} - \mu - \gamma G_{Ly} = 0,$$

$$(28)\ -x(P_y)\frac{\partial P_y}{\partial K_y} + \frac{\partial P_y}{\partial k_y}Y(\cdot) + P_y Y_{Ky} - D_g'(\cdot)G_{Ky} - D_n'(\cdot)N_{Ky} + B_a'(\cdot)A_{Ky} - P_{ky} - \gamma G_{Ky} = 0,$$

(28a) $B_a'(\cdot)A_{Ka} + P_y Y_{Ka} - P_{Ka} = 0,$

(29) $P_f F_{Lf} + B_s'(\cdot)S'F_{Lf} - \mu + \gamma\theta S'F_{Lf} = 0,$

(30) $P_f F_{Kf} + B_s'(\cdot)S'F_{Kf} - P_{Kf} + \gamma\theta S'F_{Kf} = 0,$

(26a) $L^* - L_y - L_f = 0$, and

(26b) $GHG^* - G(L_y, K_y) - \theta S\left(F(L_f, K_f)\right) = 0$

Simplifying in a manner similar to that in constructing equations (13′) through (16′), we have:

(27′) $x^*(P_y)\frac{\partial P_y}{\partial L_y} + P_y Y_{Ly} - D_g'(\cdot)G_{Ly} - D_n'(\cdot)N_{Ly} + B_a'(\cdot)A_{Ly} - \gamma G_{Ly} = \mu,$

(28′) $x^*(P_y)\frac{\partial P_y}{\partial K_y} + P_y Y_{Ky} - D_g'(\cdot)G_{Ky} - D_n'(\cdot)N_{Ky} + B_a' A_{Ky} - \gamma G_{Ky} = P_{ky},$

(28a) $B_a'(\cdot)A_{Ka} + P_y Y_{Ka} = P_{Ka},$

(29′) $P_f F_{Lf} + B_s'(\cdot)S' F_{Lf} + \gamma\theta S' F_{Lf} = \mu,$ and

(30′) $P_f F_{Kf} + B_s'(\cdot)S' F_{Kf} + \gamma\theta S' F_{Kf} = P_{Kf}.$

For the small country case, we can maximize domestic welfare simply by making the taxes and subsidies from equations (18) through (21) consistent with the conditions in equations (27′) through (30′). That is accomplished by substituting equations (27′) through (30′) into equations (18) through (21). Recalling that there are no terms of trade effects for the small country, we have:

(31) $P_y Y_{Ly} = P_y Y_{Ly} - D_g'(\cdot)G_{Ly} - D_n'(\cdot)N_{Ly} + B_a'(\cdot)A_{Ly} - \gamma G_{Ly} - s_{Ly},$

(32) $P_y Y_{Ky} = P_y Y_{Ky} - D_g'(\cdot)G_{Ky} - D_n'(\cdot)N_{Ky} - \gamma G_{Ky} + B_a'(\cdot)A_{Ky} + t_{Ky},$

(32a) $t_{Ka} = -B_a'(\cdot)A_{Ka} - P_y Y_{Ka},$

(33) $P_f F_{Lf} = P_f F_{Lf} + B_s'(\cdot)S' F_{Lf} + \gamma\theta S' F_{Lf} - s_{Lf},$ and

(34) $P_f F_{Kf} = P_f F_{Kf} + B_s'(\cdot)S' F_{Kf} + \gamma\theta S' F_{Kf} + t_{Kf}.$

After some rearranging, we have:

(31′) $s_{Ly} = B_a'(\cdot)A_{Ly} - D_g'(\cdot)G_{Ly} - D_n'(\cdot)N_{Ly} - \gamma G_{Ly},$

(32′) $t_{Ky} = D_g'(\cdot)G_{Ky} + D_n'(\cdot)N_{Ky} + B_a' A_{Ky} + \gamma G_{Ky},$

(32a′) $t_{Ka} = -B_a'(\cdot)A_{Ka} - P_y Y_{Ka},$

(33′) $s_{Lf} = B_s'(\cdot)S' F_{Lf} + \gamma\theta S' F_{Lf},$ and

(34′) $t_{Kf} = -B_s'(\cdot)S' F_{Kf} - \gamma\theta S' F_{Kf}.$

When compared with equations (22′-25′), each of these equations for socially optimal taxes and subsidies on inputs now includes an additional term containing the Lagrange Multiplier, γ, on the GHG emissions constraint. Thus, the domestic welfare maximizing taxes and subsidies on inputs now depend on the contributions of the externality outputs to domestic social benefits and costs, as well as on the value of this Lagrange Multiplier – the "shadow price" of the GHG constraint. The interpretation of γ is straightforward. If the right-hand side of the internationally-imposed limit on GHG emissions GHG^* were increased at the margin, domestic social welfare would increase by an amount γ. For positive values of γ there would be additional taxes levied on land and non-land inputs in agricultural production equal to γ multiplied by the marginal contributions of these respective inputs to GHG emissions. In contrast, subsidies on land and non-land inputs would be increased by γ

multiplied by the marginal contributions of these respective inputs to discounted carbon sequestration. For purposes of policy analysis, we must, however, consider two cases: 1) $\gamma = 0$; and 2) $\gamma > 0$.

Case 1: The Lagrange Multiplier, $\gamma = 0$

There are two circumstances in which γ can be zero. The first is where the internationally-agreed GHG constraint is not binding on the agricultural sector. The second is where optimal taxes and subsidies on inputs required to maximize domestic social welfare are those for which GHG emissions exactly coincide with the global command and control target for emissions reduction. Although logically possible, this case is unlikely to apply in practice.

The former, and more relevant, situation is where the socially optimal level of GHG emissions from agriculture based on the national social damage function for such emissions, is below the global command and control target for the country. Thus, the levels of subsidies and taxes on inputs needed to maximize domestic social welfare lead to GHG reductions in excess of the global target.

The first factor influencing the relevance of this case is how a GHG reduction target for total national emissions is allocated by sector. Countries could choose to treat agriculture more favourably that other sectors and seek to reduce emissions by focusing on other sectors. One problem with this approach is that studies have shown that, in general, agricultural emissions in developed countries are high relative to the sector's contribution to GDP (Blandford and Josling, 2009) and, as indicated earlier, this appears to apply to Norway. Allowing agriculture to opt-out of GHG reduction targets could impose a disproportionate burden on other sectors of the economy. Consequently, countries may well seek to ensure that agriculture bears its "fair share" of any emission reductions agreed at the international level.

A second issue is that for a small country, whose own emissions are likely to make a small contribution to the global total, its contribution to any domestic damage from global warming will be small relative to the potential global damage from higher global temperatures. That case may be more relevant to a large country whose emissions are large and may contribute significantly to any domestic damage from global warming. In both cases, however, the situation is complicated by the fact that recent analysis of the impact of global climate change suggests that countries in the northern hemisphere may actually gain from higher global temperatures through increased productivity in agriculture, at least over a range of higher projected temperatures (Parry *et al*., 2007). If that is so, the imposition of a globally mandated reduction in GHG emissions may well reduce domestic welfare if applied to agriculture in both small and large countries in northern hemisphere countries.

Case 2: The Lagrange Multiplier, $\gamma > 0$

If Case 1 above were to obtain, political and other difficulties in implementing a globally mandated GHG reduction target at the national level would certainly be reduced, but we can conclude that the more interesting and relevant situation is where the Lagrange Multiplier, γ, is positive.

Under this circumstance, the national social value assigned to the domestic damage attributable to GHG emissions is at odds with the global social value of the damage implicit in the assigned command and control target level for reductions and applied by the country to agriculture. Domestic social welfare could be improved by allowing for an additional unit of GHG emissions by the sector. Thus, from a domestic point of view, the assigned global command and control reduction is too high. As noted above, this is likely to apply to northern hemisphere countries in higher latitudes, such as Norway.[19] When this case applies, the achievement of domestic agro-environmental policy objectives

[19] Note, however, that Norwegian agriculture is heavily protected and its contribution to GHG emissions may already be above either a domestic or internationally optimal level. This is not reflected in our analysis since we do not incorporate non-environmental objectives, such as the redistribution of income to producers that could create this result. Changes in the level of emissions under several mechanisms (carbon taxes, alterative land-use practices, and sequestration activities) under existing agricultural policies in Norway are examined in the paper by Blandford, Gaasland and Vårdal in this session.

may be constrained by international obligations. In particular, while the international GHG constraint might dictate that land should be taken out of agricultural activities and devoted to agro-forestry, this could well constrain the supply of amenities associated with agriculture. In contrast it could reduce negative externalities associated with agricultural activities, such as pollution of water supplies.

Some Concluding Observations and Implications for Programme Design

We have argued above that the most practical way to achieve multiple (and perhaps competing) environmental objectives, including GHG mitigation in agriculture is to focus on inputs – in particular, how land is used and what inputs are applied to that land. In this way negative externalities can be reduced and the supply of positive externalities and public goods can be increased.

In the model presented above, we have assumed that non-land input bundles used in the production of agricultural goods, forestry, and landscape amenities are distinct. Thus the prices, as well as the taxes or subsidies on these input bundles, are also distinct. While this is a convenient conceptual assumption, it poses certain complications in policy implementation. To provide the appropriate policy incentives, it is necessary to be able to target taxes or subsidies on non-land inputs to their end use. The challenge of doing this would seem to be least serious in the case of agroforestry; one would only have to monitor non-land input use on the land committed to forestry. On land in agricultural production, it would be relatively easy to identify non-land inputs used specifically in agricultural production (e.g. commercial fertilizer), and others used specifically to enhance the landscape. In contrast, it may be most difficult to target a subsidy to inputs such as labour, for example, because this can be a major input needed to improve the quality of the landscape and is also used for the production of agricultural output. Ultimately one would hope to be able to target the use of all inputs to particular tasks (say labour to maintain stone walls to enhance amenities), but an acceptable alternative may be to identify representative discrete bundles of inputs (e.g. enterprise budgets) needed to accomplish specific types of landscape improvements. This strategy would in fact bundle inputs for policy purposes similar to what was done in simplifying our model, and this may indeed reflect the likelihood that many farmers make rather discrete decisions on the use of inputs in activities that promote the quality of landscape, etc. This also implies that the price of any particular input bundle is a linear function of the prices of the component inputs in the bundle. Peterson *et al*. (1999) establish that this will lead to lower bound estimates of the required subsidies for the non-land inputs and upper bound estimates of the required taxes.

A second complication is that in order to determine the optimal level of tax or subsidy one must be able to determine the net contribution of a change in the level of that input to social welfare. This is particularly challenging in cases where a specific input contributes simultaneously to positive and negative externalities – for example, inputs that both enhance landscape amenity and increase agricultural output, thereby contributing to increased nutrient pollution and GHG emissions. Clearly a judgment would have be made on whether the net contribution of a particular input is positive or negative in determining the appropriate policy approach to take – whether to tax or subsidize its use. Setting the exact level of tax or subsidy still remains challenging, but at least the correct direction of change in usage needs to be identified and pursued.

A third complication is that the primary source of GHG emissions may not be the primary input (land) *per se*, but production practices on that land. One way to address this issue is to impose specific land use conditions for the receipt of payments (e.g., cross-compliance). In Norway ruminants are a major source of emissions. Consequently, the target for emission reduction may be particular types of livestock and the ways in which these are managed (e.g., feeding practices). Taxing high emitters (e.g., cattle), the production of low-efficiency forage or extensive grazing land (which result in higher emissions per unit of livestock product output) may be options in this regard. However, the use of a headage tax would not provide an incentive to reduce emissions at the margin. In fact, there would be an incentive to maximize output per head (milk per cow or slaughter weight) which could increase emissions (through the promotion of intensification). A similar limitation would apply if the tax were applied at the product level (e.g., per gallon of milk). The impact of GHG mitigation policies,

including the promotion of sequestration, on production intensity in Norwegian agriculture are examined in the paper by Blandford, Gaasland and Vårdal in this session.

A fourth complication is that, in reality, it is likely to prove extremely difficult politically to tax land or other inputs in agriculture in order to internalize externalities. In wealthy countries there is a marked reluctance to use the "stick" approach for the sector and to focus instead on the "carrot" approach, thereby shifting the burden of paying for policies to taxpayers. The approach that is likely to be taken is one based on payment for environmental services (PES). This approach attempts to "…translate external, non-market values of the environment into real financial incentives for local actors to provide such services" (Engel *et al*., 2008, p. 664). [20] Through PES producers can be rewarded for positive externalities and public goods as well as the reduction of negative externalities. In this context, there has been considerable debate on the extent to which symmetry exists in the use of a tax or subsidy to achieve a socially efficient allocation of resources in the presence of externalities. The consensus is that a per unit payment to induce firms to reduce the polluting level of output is only likely to have an equivalent effect to a tax in the short-run because, unlike the tax, the payment would encourage firms to enter the industry (or not to leave it). This would lead to an excessive number of firms and amount of pollution (Polansky, 1979). This possibility was acknowledged by Baumol and Oates (1988) although they still argue on second best grounds for the use of subsidies to internalize negative externalities, asserting that subsidies are likely to be more acceptable to polluters (p. 290). Shortle *et al.* (1998) argue that the entry/exit problem could be addressed through a tax or subsidy that is designed to induce extra-marginal firms not to produce. In Norwegian agriculture entry into agriculture is strictly controlled so that would not seem to present a problem for the use of equivalent subsidies. However, it is quite possible that the payment of subsidies could encourage relatively inefficient and possibly highly polluting firms to remain in operation and discourage structural changes that could result in lower emissions per unit of value added. The analysis by Blandford, Gaasland and Vårdal in this session, suggests that this would not be major issue for policies to reduce GHG emissions in Norwegian agriculture since major adaptations would occur through changes in practices on existing farms and the structure of output.

A fifth complication is that the size of the subsidy will probably have to be varied at the level of individual farms (or at least for groups of farms producing similar products with similar land resources and production technology) in order to achieve the desired outcome. One advantage of a tax in correcting a negative externality is that the tax falls most heavily on firms that are high users of the polluting input. It also induces a reduction in the inefficient uses of that input, if that exists. Consistent with the call by Randall (2007) to target policies at the local level, Fraser (2009) shows that the use of a subsidy that does not account for differences among farms in the provisions of environmental goods and services is likely to lead to a divergence between the actual and socially optimal level of provision. This divergence could well be exacerbated if participation is voluntary and if the government has incomplete information about the quality of a farmer's land, production technology, etc. Even if policies are designed appropriately to recognize this diversity across farms, this asymmetric information will increase the costs of achieving a particular environmental objective (e.g. Peterson and Boisvert, 2001).[21] The extent of these increased costs is implicitly the value of

[20] The conceptual issues surrounding both the measurement and valuation of jointly produced non-commodity outputs from multifunctional agriculture are well known (e.g. Hoehn and Randall, 1989, and Randall, 2002). In his discussion of progress and promise for the development of such a valuation framework, Randall (2007, p. 29) argues that "[t]he idea of systematically green-pricing the non-commodity outputs of multifunctional agriculture raises serious challenges for policy-makers and the valuation specialists who would provide empirical support for the effort." Efficient green prices must be targeted to the local level and green production must be monitored with at least a credible threat of penalty for noncompliance. While perfection is unattainable, Randall is convinced that performance of multifunctional agriculture would be much improved through good faith efforts to implement green-pricing, targeting, and monitoring.

[21] It can also be shown that the additional participation incentives that would be needed as a result of asymmetric information about land quality, etc. would remain inadequate if they were designed under the assumption of risk neutrality when in fact producers are risk-averse (Peterson and Boisvert, 2004). These

information, and these costs may decline over time as information about the farms is gathered through programme implementation and monitoring for non-compliance. The use of a bidding process by farmers wishing to participate in schemes can also reveal the private costs of compliance and allow these to be compared to potential social benefits (see the paper by Blandford and Hodge in this session).

Finally, the use of a subsidy is likely to involve higher transactions costs than a tax. Information is not costless. Farmers who are required to prepare and submit information in order to participate in schemes will incur costs in doing so. Alternatively, if payment levels are determined by an environmental agency on the basis of estimates of costs of provision (e.g., farm budgets) the agency may incur significant costs in the design and implementation of a programme.[22] If the bulk of transactions costs are incurred by those targeted (producers) the subsidy may have to be correspondingly larger than the tax equivalent to induce them to comply, particularly with a voluntary scheme. If the scheme is mandatory, the failure to cover transactions costs will likely result in a suboptimal outcome (under-provision of a positive externality, over-supply of a negative externality). At the very least it will generate compliance issues. If private transactions costs are fully compensated, social surplus is likely to be reduced since part of the social benefit from correcting the externality will be absorbed by the cost of instrument inefficiency.

References

Baumol, W. and W. Oates (1988). *The Theory of Environmental Policy*. 2th ed. Cambridge: Cambridge University Press.

Beattie, B., C. R. Taylor and M. Watts (2009). *The Economics of Production*, Malabar, FL: Krieger Publishing Company.

Blandford, D. and T. Josling (2009). Greenhouse Gas Reduction Policies and Agriculture: Implications for Production Incentives and International Trade Disciplines. Issue Brief No. 1. Geneva, Switzerland and Washington, DC: International Centre for Trade and Sustainable Development and International Food and Agricultural Trade Policy Council.

Boisvert, R. (2001). "A Note on the Concept of Jointness in Production," Annex 1 in *Multifunctionality: Towards an Analytical Framework*. OECD, Paris.

Casamatta, G., G. Rausser, and L. Simon (2011). "Optimal Taxation with Joint Production of Agriculture and Rural Amenities," *Resource and Energy Economics* 33, pp. 544–553.

Cattaneo, A., D. Hellerstein, C. Nickerson, and C. Myers (2006). Balancing the Multiple Objectives of Conservation Programs. Economic Research Service, US Department of Agriculture, Washington, DC. Economic Research Report No. 19, May.

Chang, H., R. Boisvert and D. Blandford (2005). "Achieving Environmental Objectives under Reduced Domestic Agricultural Support and Trade Liberalization: An Empirical Application to Taiwan," *Agricultural and Resource Economics Review* 34, pp. 16-31.

Coate, S. and S. Morris (1995). "On the Form of Transfers to Special Interests," *Journal of Political Economy* 103, pp. 1210–1235.

additional complications due to differences in farmer's risk preferences, however, are likely to be given little weight in light of the other sufficient challenges in any good-faith efforts to design programs to deal with these multiple agro-environmental policy objectives.

[22] A discussion of transactions costs and estimates for a range of agricultural policies, including agri-environmental programmes, is provided by OECD (2007).

Dillman B. and Bergstrom, J. (1991). "Measuring Environmental Amenity Benefits of Agricultural Land." In: N. Hanley (ed.) *Farming and Countryside*. Wallingford, UK: CAB International.

Drake, L. (1992). "The Non-market Value of Swedish Agricultural Landscape," *European Review of Agricultural Economics* 19, pp. 351–364.

Engel, S., S. Pagiola, and S. Wunder (2008). "Designing Payments for Environmental Services in Theory and Practice: An Overview of the Issues," *Ecological Economics* 65, pp. 663-674.

Farm Service Agency, US Department of Agriculture (2011). Conservation Reserve Program Sign-up 41 Environmental Benefits Index (EBI). Washington, DC. Fact Sheet, January. Available at: http://www.fsa.usda.gov/Internet/FSA_File/crp_41_ebi.pdf

Fraser, R. (2009). "Land Heterogeneity, Agricultural Income Foregone and Environmental Benefit: An Assessment of Incentive Compatibility Problems in Environmental Stewardship Schemes." Journal of Agricultural Economics 60, pp. 190-201.

Harvey, D. (2003). "Agri-environmental Relationships and Multi-functionality: Further Considerations," *The World Economy* 26, pp. 705–725.

Hoehn, J. and A. Randall (1989). "Too Many Proposals Pass the Benefit Cost Test," *American Economic Review* 79, pp. 544-551.

Hodge, I. (2000). "Agri-environmental Relationships," *The World Economy* 23, pp. 257–273.

Holtermann, S. (1976). "Alternative Tax Systems to Correct for Externalities, and the Efficiency of Paying Compensation," *Economica* 43, pp. 1-16.

Huso, B. (2010). "Experiences in Using Agricultural Environmental Indicators as a Policy Tool in the Norwegian Agri-environmental Programme." Paper presented at the OECD Workshop on Agri-environmental Indicators: Lessons Learned and Future Directions, Leysin, Switzerland. Available at: http://www.oecd.org/dataoecd/31/16/44808044.pdf

Lankoski, J. and M. Ollikainen (2003). "Agri-environmental Externalities: A Framework for Designing Targeted Policies," *European Review of Agricultural Economics* 30, pp. 51–75.

Lyssandtræ, F. (2006). "Links between Agricultural Production and Rural Development: The Norwegian Experience". In D. Diakosavvas (ed.) Coherence of Agricultural and Rural Development Policies, Paris: OECD.

Organisation for Economic Co-operation and Development (2007. *The Implementation Costs of Agricultural Policies*, Paris.

Organisation for Economic Co-operation and Development (2011). Producer and Consumer Support Estimates Database. Trade and Agriculture Directorate. http://www.oecd.org

Parry, M.L, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.) (2007), *Contribution of Working Group II to the Fourth Assessment Report on Climate Change, 2007*, Cambridge University Press, Cambridge, UK and New York.

Peterson, J., R. Boisvert, and H. de Gorter, H. (1999). "Multifunctionality and Optimal Environmental Policies for Agriculture in an Open Economy." Department of Agricultural, Resource, and Managerial Economics, Cornell University. Ithaca, NY. Working Paper 99-29.

Peterson, J., R. Boisvert, and H. de Gorter. 2002. "Environmental Policies for a Multifunctional Agricultural Sector in Open Economies," *European Review of Agricultural Economics* 29, pp. 127-142.

Peterson, J. and R. Boisvert (2004). "An Incentive Compatible Self-Compliant Pollution Policy under Asymmetric Information on Both Risk Attitudes and Technology", *American Journal of Agricultural Economics*, 86, pp. 291-306.

Peterson, J. and R. Boisvert (2004). "Control of Nonpoint Source Pollution Through Voluntary Incentive-based Policies: An Application to Nitrate Contamination in New York", *Agricultural and Resource Economics Review, 30, pp.* 127-138.

Plott, C. (1966). "Externalities and Corrective Taxes," *Economica* New Series 33, pp. 84-87.

Polinsky, A. "Notes on the Symmetry of Taxes and Subsidies in Pollution Control," Canadian Journal of Economics 12, pp. 75-83.

Randall, A. (2002). "Valuing the Outputs of Multifunctional Agriculture," *European Review of Agricultural Economics* 29, pp. 289-307.

Randall, A. (2007). "A consistent valuation and pricing framework for non-commodity outputs: Progress and prospects" *Agriculture, Ecosystems and Environment* 120, pp. 21–30.

Rose, S. and B. McCarl (2010). "U.S. Biomass Supply for Electricity Generation: Climate Policy Implications and Carbon Neutrality," Contributed Paper at the IATRC Public Trade Policy Research and Analysis Symposium Universität Hohenheim, Stuttgart, Germany. June 27–29.

Shortle, J., R. Horan and D. Abler (1998). " Research Issues in Nonpoint Pollution Control." *Environmental and Resource Economics* 11, pp. 571-585.

Shumway, C., R. Pope and E. Nash (1984). "Allocable Fixed Inputs and Jointness in Agricultural Production: Implications for Economic Modeling," *American Journal of Agricultural Economics* 66, pp. 72-78.

Spulber, D. (1985). "Effluent Regulation and Long-run Optimality," *Journal of Environmental Economics and Management* 12, pp. 103-116.

Stevens, B. (1988). "Fiscal Implications of Effluent Charges and Input Taxes," *Journal of Environmental Economics and Management* 15: 285-296.

Walker, T., Study Team Leader (2010). Biomass Sustainability and Carbon Policy Study. Report prepared for the Commonwealth of Massachusetts, Department of Energy Resources by Manomet Center for Conservation Sciences, Manomet, MA.