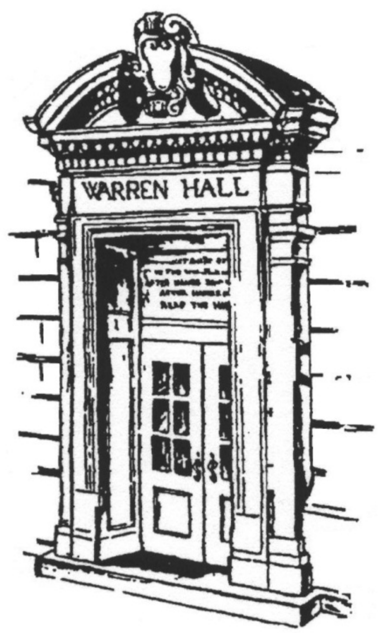
WP 2011-21

December 2011



Working Paper

Dyson School of Applied Economics and Management
Cornell University, Ithaca, New York 14853-7801 USA

Meeting multiple policy objectives under GHG emissions reduction targets

Richard N. Boisvert and David Blandford

It is the policy of Cornell University actively to support equality of educational and employment opportunity. No person shall be denied admission to any educational program or activity or be denied employment on the basis of any legally prohibited discrimination involving, but not limited to, such factors as race, color, creed, religion, national or ethnic origin, sex, age or handicap. The University is committed to the maintenance of affirmative action programs which will assure the continuation of such equality of opportunity.

Meeting multiple policy objectives under GHG emissions reduction targets

Richard N. Boisvert
Professor
Charles H. Dyson School of Applied Economics and Management
Cornell University
Ithaca, NY 14850
e-mail: rnb2@cornell.edu

David Blandford
Professor
Department of Agricultural Economics and Rural Sociology
Pennsylvania State University
University Park, PA 16802

Paper presented at a
Workshop on Mitigation of Greenhouse Gas Emissions by the Agricultural Sector
University of Bergen
Bergen, Norway
October 3-4, 2011

Meeting multiple policy objectives under GHG emissions reduction targets

Abstract

Since many countries already pursue a range of environmental objectives for agriculture, in particular the supply of positive externalities or public goods (e.g., wildlife habitat, water supply management, provision of landscape amenities) as well as the reduction of negative externalities, such as soil erosion or water pollution, efforts to reduce GHG emissions may have to be balanced against other environmental objectives. We examine this problem by considering 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. In the case where the socially optimal level of GHG emissions from agriculture based on the national social damage function for GHG emissions is below the global command and control target for the country, the levels of subsidies and taxes on inputs needed to maximize domestic social welfare lead to GHG reductions in excess of the global target. In contrast, the national social value assigned to the domestic damage due to GHG emissions could be at odds with the global social value of the damage implicit in the command and control target level of emission reductions assigned to the country and applied by that country to agriculture. In this case, 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 global command and control target level of reductions assigned to the country is too high.

We also argue that the most practical way to achieve multiple environmental objectives, including GHG mitigation in agriculture is to focus on inputs – specifically 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. Since it is unlikely to prove politically acceptable to use explicit taxes on inputs to correct for negative externalities in agriculture, a more likely approach is one based on payments for environmental services designed specifically to translate the non-market values of the environment services into financial incentives for local actors to provide such services.

Meeting multiple policy objectives under GHG emissions reduction targets

By

Richard N. Boisvert and David Blandford

Introduction

Despite the failure of the 2009 U.N. Climate Conference in Copenhagen, efforts continue to reach agreement on binding global commitments for reductions in greenhouse gas (GHG) emissions. Any such future agreement will likely involve the agricultural sector, which heretofore has been exempted from most national initiatives to reduce carbon emissions.

Many countries already pursue a range of environmental objectives for agriculture, in particular the promotion of the supply of positive externalities or public goods (e.g., wildlife habitat, water supply management, provision of landscape amenities) as well as the reduction of negative externalities, such as soil erosion or water pollution. The aim of reducing GHG emissions may therefore have to be balanced against other environmental objectives. Policies will have to be designed to address multiple environmental outcomes.

In this paper we examine this problem by considering 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.

The Model

Our model of agricultural production contains the essential components for analyzing 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 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, but their composition is allowed to differ in the production of commodity and non-commodity outputs from agriculture.

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,[1] and cultural landscape is assumed to improve with the intensity of management, as measured by K_a/L_y.[2] 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.[3]

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') $N = N(L_y, K_y)$.

---

[1] 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).

[2] 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 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.

[3] 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 collections of machinery and buildings, odor, manure disposal facilities, etc. related to large scale animal agriculture could well 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.

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.[4]

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 those 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 (e.g. 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 different growth patterns), which, for our purposes, could also be reflected in the non-land input intensity of production, K_f/L_f.[5]

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-*

[4] We exclude the use of specific input bundles designed to reduce negative externalities in this formulation. However, we note the implications of a more complex specification later in the paper.
[5] 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.

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.

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. [6] Furthermore, there is a fixed quantity of land, $L^* = L_y + L_f$. [7] 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

[6] We subsequently relax the assumption that the price of agricultural output is fixed.
[7] 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 increase forestry output there must be a reduction both in land allocated to agricultural production, and in agricultural output (Boisvert, 2001). This cause for joint production would not exist if land could be purchased at a fixed price or if prices were determined in a competitive land market.

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.[8]

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) $\max_{L_y,K_y,L_f,K_f,K_a} P_y Y\left(L_y, K_y, K_a\right) + P_f F\left(L_f, K_f\right) + P_g G\left(L_y, K_y\right) + P_n N\left(L_y, K_y\right) +$

$PaALy,Ka,Ky + PsSFLf,Kf - PkyKy + PkaKa + PkfKf + \mu L* - Ly - Lf.$

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* represent 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

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

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.

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.[9]

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

[9] 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.

(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 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 reestablish equilibrium.

A similar line of reasoning applied to equation (10) would lead one 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 a bit 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 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 reestablish 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 product in the production of agricultural output, GHG emissions, and nutrient pollution are positive, but declining. Therefore, the marginal 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 it would be without 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 be negative as well, and to reestablish 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.[10]

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

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

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 must equal 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 not of much help in practice. As Peterson, *et al*. (2002) point out, 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 act on observable outputs and inputs.

In what follows, we build on previous results from the trade and environmental economics literature. For this 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.[11]

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.

The Welfare Maximization Problem

Social welfare can be represented as the sum of consumer and producer surplus.[12] 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 to generate landscape amenities (K_a):

$$(11) max \int_{P_y(Ly,Ky)}^{\infty} x(\widetilde{P_y})d\tilde{P}_y + P_y(L_y,K_y)Y(L_y,K_y,K_a) + P_f F(L_f,K_f) - D_g[G(L_y,K_y)]$$

$$- D_n[N(L_y,K_y)] + B_a[A(L_y,K_a,K_y)] + B_s\left[S\left(F(L_f,K_f)\right)\right]$$

$$- [(P_{ky}K_y + P_{ka}K_a + P_{kf}K_f)] + \mu[L^* - L_y - L_f]$$

[11] 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 the optimal input taxes for a single externality.

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

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.[13] 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) $Y = x(P_y) + x^*(P_y)$

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.[14]

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 to generate landscape amenities (K_a). The first-order necessary conditions for a maximum are:

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

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

[13] 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, if these forests are used as biomass fuel, there is growing evidence that such fuels are not carbon neutral, a view generally held by many promoting the use of biomass fuels. 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).

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

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

(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 from any 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 sides 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—using 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.[15]

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

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

(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:

[15] Since these inputs are allocable between the two sets of joint products, there is a need to be able to differentially tax or subsidize their use. 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.

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

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

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

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

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

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') $t_{Ka} = -B_a'(\cdot)A_{Ka} - P_yY_{Ka}$,

(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, the additions to the private value of agricultural output add to the social benefits of improvements in landscape amenities and t_{Ka} will be unambiguously negative (a subsidy).[16] 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 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.[17]

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

[16] 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.

[17] To reflect reality, we have throughout argued that the 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 distinct as well. This presents no problems conceptually, but this does present certain complications in policy implementation. To administer the appropriate policy incentives, it is necessary to be able to target the taxes or subsidies on these non-land inputs to their end use. The problems in doing this would seem to be least serious in the case of agroforestry; one would only have to monitor input non-land input use on that land committed to forestry. On land in agricultural production, it would be easy to identify some of the 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 labor, for example, because it can be a major input needed to improve the quality of the landscape, but it is also used on the same land for the production of agricultural output. Ultimately one would hope to be able to target the use of all inputs to particular tasks (say labor 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 similarly to what is done to simplify our model, and this may indeed reflect the likelihood that many farmers do 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.

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

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 these emission reduction targets, 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 these 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:

$$(26) max \int_{P_y(Ly,Ky)}^{\infty} x(\widetilde{P_y}) d\widetilde{P}_y + P_y(L_y, K_y)Y(L_y, K_y, K_a) + P_f F(L_f, K_f) - D_g[G(L_y, K_y)]$$

$$- D_n[N(L_y, K_y)] + B_a[A(L_y, K_a, K_y)] + B_s\left[S\left(F(L_f, K_f)\right)\right]$$

$$- [(P_{ky}K_y + P_{ka}K_a + P_{kf}K_f)] + \mu[L^* - L_y - L_f]$$

$$+ \gamma\left[GHG^* - G(L_y, K_y) + \theta S\left(F(L_f, K_f)\right)\right]$$

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 equation (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 equation (22’-25’), each of these equations for socially optimal taxes and subsidies on inputs now includes an additional term that contains 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, the subsidies to 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) where $\gamma = 0$ and 2) where $\gamma > 0$.

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 targets 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 GHG 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 applicable to total national emissions is allocated by sector. Countries could choose to treat agriculture more favorably that other sectors and seek to reduce their 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 very high relative to the sector's contribution to GDP (Blandford and Josling, 2009). 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.

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 on the basis of the discussion above we can concluded that the more interesting and relevant situation is where the Lagrange Multiplier,γ, is positive.

Under these circumstances, the national social value assigned to the domestic damage due to GHG emissions is at odds with the global social value of the damage implicit in the command and control target level of emission reductions assigned to the country and applied by that 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 global command and control target level of reductions assigned to the country is too high. As noted above, this is likely to apply to northern hemisphere countries in higher latitudes, such as Norway.[18] When this case applies, the achievement of domestic agro-environmental policy objectives 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.

[18] Note, however, that Norwegian agriculture is heavily protected and its contribution to GHG emissions may therefore 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.

Implications for Program Design

We have argued above that the most practical way to achieve multiple environmental objectives, including GHG mitigation in agriculture is to focus on inputs – specifically 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. Since it is unlikely to prove politically acceptable to use explicit taxes on inputs to correct for negative externalities in agriculture, 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). Through PES producers can be rewarded for positive externalities and public goods as well as the reduction of negative externalities. The implementation of a PES approach requires that positive and negative environmental contributions be clearly identified and that payments be directed to achieving the maximum social benefit. In this part of the paper we consider the use of such an approach using the Conservation Reserve Program (CRP) as an example.

The CRP program

The CRP, which was originally introduced in the 1985 Farm Bill, is a voluntary program that pays agricultural landowners an annual rental payment and cost-sharing assistance to establish long-term, resource conserving practices on eligible land. Contracts lasting from 10 to 15 years typically involve planting and maintaining covers to control soil erosion, improve water and air quality, and enhance wildlife habitat. The aim of the program, therefore, is to change existing land use in order to increase the supply of environmental services.

The CRP involves a competitive bidding system. Farmers offer eligible acreage for enrollment in the program and specify the rental payment that they are prepared to accept. Applications are ranked on the basis of an Environmental Benefits Index (EBI) which assigns a point score based on an offer's environmental characteristics. The factors incorporated into the EBI are known to farmers in advance of submitting their bids. Those used for the sign-up announced in January 2011 are summarized in Table 1. In addition to environmental criteria the costs of accepting particular parcels under the program are also taken into account in computing a final score since there are limits on the maximum acreage that can be enrolled in the program and on available funds.

The design of the EBI reflects a judgment of which characteristics of land parcels and the practices applied to them would generate the highest environmental benefits, relative to costs, if an offer to enroll them in the program were to be accepted. Of the maximum possible point score (excluding the scoring for costs) of 400 points, 240 are unambiguously allocated to negative externalities of crop production (lower water and air quality and increased soil erosion), 110 are unambiguously allocated to promoting the supply of public goods (wildlife habitat and carbon sequestration). The remaining 50 points (enduring benefits) apply to increasing the probability of securing continued reduction in externalities and an enhanced supply of public goods beyond the period of enrollment in the program.

The weightings attached to each of the factors, both the total points allocated to a particular characteristic (e.g., contribution to wildlife habitat, category N1, versus enhancement of water quality N2) and the allocation of points within these characteristics (e.g. aspects of the contribution to wildlife habitat within N1) reflect a particular set of preferences for the range of possible outcomes. Most of the characteristics that are rated are based on scientific judgments, although science may offer only limited guidance as to how those should be weighted. Some of the preferences for characteristics are based on an absolute threshold, i.e., no points are awarded unless a particular characteristic is present or a threshold value for that characteristic is met (e.g., N2a). Other factors (e.g., N1a) are continuous over a given range. For those variables it is possible to determine implied trade-offs among characteristics at the margin. This is not possible for the discontinuously rated factors. Even in the former case, the interpretation of marginal valuations among factors is not straightforward due to differences in metrics. In this context, the scaling of individual factors is critical (e.g., the construction of the indices used for leaching and sedimentation in N2) and the factors themselves may not be comparable. For example, it would be difficult to determine what a marginal change in the measure of cover benefits (N1a) relative to a marginal change in the erodability index (N3) across parcels would actually mean in terms of overall environmental quality.

Despite these limitations, the index approach used in the EBI seems to hold considerable promise for developing a structured approach to designing a payment scheme to enhance the supply of environmental goods and to reduce the supply of environmental bads (Cattaneo *et al*., 2006). In particular, it has the following advantages:

1. There is an explicit identification of the environmental factors that are valued by policymakers and the relative weights that are placed on them.
2. The factors are known to producers in advance, such that they are in a position to judge whether it would be worthwhile for them to participate in the program.
3. A competitive bidding process provides an opportunity for taxpayers to get the best value for money in terms of improving environmental quality – producers will place bids that are in line with private costs of meeting the contract requirements and these may be below the social costs or benefits involved.

In contrast, there are a number of disadvantages:

1. The way that the index is constructed (factors included, the way these are measured and the points allocated to them) may not produce the most desirable or efficient outcome in terms of enhanced environmental quality. In short, the EBI may be poorly constructed.

2. There may be learning by doing over time or implicit collusion among producers such that bids tend to converge around the maximum rental rate that the policymakers are prepared to offer under the program.
3. The use of the index may involve relatively high transactions costs in terms of the preparation of bids by producers, evaluation of the bids by policymakers, and monitoring of compliance under contracts.

Application of the EBI approach in the context of climate change mitigation in Norway

Norway already has in place a set of environmental programs for agriculture, involving national, regional and local components. At the regional (county) level priorities center on the protection of the cultural landscape (e.g., maintenance of grazing systems to preserve open space) and pollution prevention. Local authorities are allowed to prioritize the use of resources provided by central government both in terms of the balance between the two principal objectives and the spatial allocation of funds (Huso, 2010). The elements of a framework are already in place, therefore, to develop a targeted approach to the use of payments to achieve a range of environmental objectives, including climate change mitigation objectives. In what follows, we shall consider how to design an approach for meeting the externally imposed GHG mitigation objective (along the lines of that specified in our model) while also taking into account other environmental objectives.

As in our earlier model, we assume that a target has been established for reducing GHG emissions in agriculture and that carbon sequestration in the sector can be used to help meet that goal. We assume that farmers will be offered a payment to encourage them to divert land from agricultural production to agro-forestry in addition to payments for achieving other environmental objectives.[19] The diversion payment might cover the establishment costs for forest

[19] Investments in some mitigation activities that are not directly linked to the use of land, such as the use of methane digesters for animal waste, could also be targeted through the use of incentive payments. Cost sharing is used as the primary approach for promoting investments that improve environmental quality in the United States, for example, in the Environmental Quality Incentives Program (EQIP).

plantings and compensation for net income foregone over the life of the planting, either through a series of fixed annual payments or a lump sum based on a discounted stream of future income.[20] If cost were the only consideration diversion payments would be targeted to regions where the opportunity costs of agro-forestry are low and where the sequestration potential from forestry is high. However, since there are multiple environmental objectives, the determination of how to allocate diversion payments based on the use an EBI would seem to be more appropriate since GHG mitigation would have to be balanced against these in selecting which land parcels to include in the diversion program. The EBI has more general applicability since it can also be used to identify where the values of other environmental services are high and where payments for those should be directed.

As for the CRP the application of an EBI for Norway would need to be focused at an appropriate geographical scale. Given the mix of environmental attributes across farms and locations, it would not be feasible (or efficient in terms or outcomes) to provide a single undifferentiated payment to farmers for supplying categories of attributes. Payments would need to be spatially differentiated to reflect differences in the ability of farmers to supply those attributes. The current county-based approach used for agri-environmental programs in Norway provides a framework for this.

In the Norwegian case, the public good component would have to be expanded beyond the enhancement of wildlife habitat under the CRP to include other aspects of landscape amenities. This factor is already reflected at the local level in Norwegian agri-environmental program. Different weightings would need to be developed for other factors. For example, in the

[20] This would satisfy the conditions for inclusion of environmental payments in the so-called ‘green box’ category of support under the Agreement on Agriculture in the WTO. Note, however, that the high level of protection provided to Norwegian agriculture would increase the magnitude of these payments since presumably they would be linked to domestic prices for agricultural products rather than world prices.

CRP EBI very little weight is given to carbon sequestration, whereas this would be a much more significant element in a Norwegian EBI that had the promotion of carbon sequestration as a primary goal.

It is an open question as to whether a bidding process should be used. This has a number of advantages and disadvantages as outlined above. A major reason for using that approach in the US has been to try to achieve the maximum environmental effects given a constraint on the area that can be enrolled in the scheme, and the amount of available funding. Norwegian policymakers may not face the same imperatives. In the Norwegian case, a major function of the EBI might be to provide transparency in the determination of payments to particular parcels of land that are brought under environmental programs that have multiple objectives.

Table 1. Summary of factors and point scores in the 2011 EBI for the US Conservation Reserve Program

Factor	Characteristics	Point score
N1 Wildlife		Max = 100
N1a Cover benefits	Different planting mixtures rated in terms of benefits to wildlife	0-50
N2a Enhancement	Specific practices judged to enhance wildlife habitat, e.g., establishment of pollinator habitat	0, 5, 20
N3a Priority zones	Locations designated as high priority for wildlife improvement	0 or 30
N2 Water quality		Max = 100
N2a Location	Locations designated as high priority for water quality improvement	0 or 30
N2b Groundwater	Leaching index weighted by population using groundwater	0-25
N3c Surface water	Sedimentation index weighted by population using surface water	0-45
N3 Erosion	Erodability index	Max = 100
N4 Enduring Benefits	Likelihood that practices will remain in place, e.g., conversion of land to woodland	Max = 50
N5 Air Quality	From reduction in wind erosion	Max = 50
N5a Wind erosion impacts	Potential for wind erosion damage weighted by population potentially affected	0-25
N5b Wind erosion soils	Particular soils that are highly erodible	0 or 5
N5c Air quality zones	Location in zone not meeting standards	0 or 5
N5d Carbon sequestration	Weighted average of carbon sequestration from certain practices	3-10
N6 Cost	Cost of environmental benefits per dollar of expenditure	Max = ?
N6a Cost	Point value determined after sign-up based on actual offer data – weights offers with rental rates more highly	
N6b Offers below maximum payment rate	Points for percentage that offer is below maximum rate	0-25

Source: Based on FSA, USDA (2011).

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 Center 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.

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: 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: 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

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: 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.

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* 29:127-142.

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

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

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.

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: 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," a report prepared for: Commonwealth of Massachusetts, Department of Energy Resources by Manomet Center for Conservation Sciences, Manomet, MA.

OTHER A.E.M. WORKING PAPERS

WP No	Title	Fee (if applicable)	Author(s)
2011-20	The Theory of Biofuel Policy and Food Grain Prices		Drabik, D.
2011-19	Factors Influencing Adoption of Integrated Pest Management in Northeast Greenhouse and Nursery Production		Gómez, M.
2011-18	Urban Agglomeration Economies in the U.S. Greenhouse and Nursery Production		Gómez, M.
2011-17	Evaluating the Impact of the Fruit and Vegetable Dispute Resolution Corporation on Regional Fresh Produce Trade among NAFTA Countries		Gómez, M., Rizwan, M. and N. Chau
2011-16	Does the Name Matter? Developing Brands for Patented Fruit Varieties		Rickard, B., Schmit, T., Gómez, M. and H. Lu
2011-15	Impacts of the End of the Coffee Export Quota System on International-to-Retail Price Transmission		Lee, J. and M. Gómez
2011-14	Economic Impact of Grapevine Leafroll Disease on Vitis vinifera cv. Cabernet franc in Finger Lakes Vineyards of New York		Atallah, S., Gomez, M., Fuchs, M. and T. Martinson
2011-13	Organization, Poverty and Women: Andhra Pradesh in Global Perspective		Dev., S., Kanbur, R. and G. Alivelu
2011-12	How have agricultural policies influenced caloric consumption in the United States?		Rickard, B., Okrent, A. and J. Alston
2011-11	Revealing an Equitable Income Allocation among Dairy Farm Partnerships		Dressler, J. and L. Tauer
2011-10	Implications of Agglomeration Economics and Market Access for Firm Growth in Food Manufacturing		Schmit, T. and J. Hall
2011-09	Integration of Stochastic Power Generation, Geographical Averaging and Load Response		Lamadrid, A., Mount, T. and R. Thomas
2011-08	Poor Countries or Poor People? Development Assistance and the New Geography of Global Poverty		Kanbur, R. and A. Sumner

Paper copies are being replaced by electronic Portable Document Files (PDFs). To request PDFs of AEM publications, write to (be sure to include your e-mail address): Publications, Department of Applied Economics and Management, Warren Hall, Cornell University, Ithaca, NY 14853-7801. If a fee is indicated, please include a check or money order made payable to Cornell University for the amount of your purchase. Visit our Web site (*http://aem.cornell.edu/research/wp.htm)* for a more complete list of recent bulletins.