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Activity level, emission intensity, and optimal GHG abatement policy: An application to Norwegian agriculture

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Abstract

Despite the failure of the U.N. Copenhagen climate conference in December 2009 efforts are continuing to reach agreement on binding global commitments on greenhouse gas (GHG) emissions. At the same time, efforts are still underway to conclude the Doha Round of trade negotiations through the World Trade Organization (WTO). Both of these agreements could have a significant impact on the level of activity in agriculture and the GHG emissions that it generates. In this paper we explore strategies to comply with both trade liberalization and GHG emission reduction commitments. We examine the implications of trade liberalization and a carbon tax, both of which affect agricultural output, as means of achieving emission reductions. We emphasize two diametrically different responses to a carbon tax. One adaptation is to change the way agricultural commodities are produced, i.e., choosing less polluting techniques, which we argue will require more land per unit of output. The second response is to use agricultural land for carbon sequestration purposes (offsets), e.g., for perennial grasses or forestry. We show that when an offset option is introduced, production intensity tends to increase, such that emissions per unit of output rise. The theoretical results are illustrated by using a partial equilibrium model of the Norwegian agricultural sector.

1. Introduction

Despite the failure of the U.N. Copenhagen climate conference in December 2009 efforts are continuing to reach agreement on binding global commitments on greenhouse gas (GHG) emissions. Although agriculture has been exempted so far from most national carbon reduction initiatives, it is likely that the sector will be included in future GHG tax or quota systems. At the same time, efforts are still underway to conclude the Doha Round of trade negotiations through the World Trade Organization (WTO). Potential future climate and trade agreements will affect the relative profitability of different farming systems, the level of agricultural activity, and GHG emissions generated by the sector.

In this paper we explore viable strategies for complying with both trade liberalization and GHG emission reduction commitments. Our analysis takes the perspective of a small country whose agriculture is currently protected and whose political aim is to keep agricultural activity as high as possible within the constraints imposed by multinational agreements. We examine the implications of trade liberalization and a carbon tax, both of which affect agricultural output, as means of achieving emission reductions. We emphasize two diametrically different responses to a carbon tax. One adaptation is to change the way agricultural commodities are produced, i.e., choosing less polluting techniques, which we argue will require more land per unit of output (referred to as lower *production intensity*). The second response is to use agricultural land for carbon sequestration purposes (offsets), e.g., for perennial grasses or forestry. We show that when an offset option is introduced, production intensity tends to increase, such that emissions per produced unit of output rise.

Our paper is divided into two parts. In the first part we use a simple analytical model to demonstrate the main mechanisms through which trade liberalization and climate change policies affect output and emissions. Second, we use a comprehensive partial equilibrium model of the Norwegian agricultural sector (Jordmod) to examine the consequences for Norwegian agriculture.

In the analytical model we use the simplifying assumption that the agricultural sector receives support solely in the form of output subsidies. We examine the effects of trade liberalization by decreasing these subsidies, which, consequently, lowers farm gate prices. Since factor prices are unchanged in this case, there is no change in the way production takes place. The impact on emissions is felt through a scale effect, i.e., production declines and so do GHG emissions. The trade liberalization results are then compared to a case in which an equivalent carbon emission reduction is achieved through a carbon tax. Using a carbon tax, we expect a shift towards less polluting agricultural techniques. This can indeed happen, but if carbon offsets are possible we demonstrate that the opposite may actually occur. The reason is that when offsets are an option, land that remains in agricultural production is implicitly taxed (land diverted to offsets is rewarded). Farmers then have an incentive to intensify production on remaining land by using productivity enhancing inputs, even if these cause pollution, to release land for offset activities. We call this phenomenon *perverse intensity reversal*.

Regardless of whether perverse intensity reversal applies, agricultural production will be larger with the carbon tax compared to the trade liberalization case. We also show that if the sector has a wide range of possibilities for choosing between more or less polluting techniques (the substitution elasticity is high), we may end up in a situation where production is higher compared to the base case.

In the final section of the paper we assess the consequences for Norwegian agriculture. We use a partial equilibrium model of the Norwegian agricultural sector (Jordmod) that includes demand and supply relations and the most important commodities, regions, technologies and policy instruments. Coefficients for GHG emission and sequestration are attached to activities and production factors in the model. The point of departure is the model's representation of current policy (base solution), which is characterized by prohibitive tariffs and large subsidies that make it possible to maintain a high degree of self-sufficiency in spite of climatic disadvantages. GHG emissions from agriculture constitute an estimated 8 per cent of the Norwegian total although the sector accounts for only 1 percent of GDP. A major part of these emissions is associated with ruminant animals (which are important in Norwegian agriculture) and high intensity in the use of fertilizer (to compensate for climatically-related low yields).

In the run up to the Copenhagen climate conference, Norway proposed a 30 percent reduction in economy-wide GHG emissions by 2020 (compared to the 1990 level). In the analysis we assume that agriculture has to reduce its emissions by this percentage in the 2003 base year used in the model.[1] For the trade liberalization scenario we use the latest proposal for support reduction commitments prepared by the previous chair of the WTO agricultural committee, Crawford Falconer (WTO, 2008)

The trade liberalization proposals in the Doha round are characterized by weak disciplines with respect to the use of trade-distorting support. Consequently, our results show that they would not produce a sufficiently large cut in either agricultural production or GHG

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[1] Norway's GHG emissions in 2003 were below the level in 1990, so this overstates the actual reduction that would be required (Statistics Norway, 2011).

emissions. To achieve the assumed 30 per cent cut, more effective trade liberalization is required, whose effects can then be compared to a more targeted abatement policy involving a tax on GHG emissions.

While the decrease in GHG emissions is mainly due to lower production under trade liberalization, the imposition of a carbon tax generates a change in production intensity (e.g., the use of fertilizer; tilled versus no-till cropping). When carbon offsets are not an option for farmers, production intensity decreases (the output/land ratio falls), while the opposite applies when there is a high offset parameter. In Norway's case, and indeed from a wider perspective, these results raise questions about consistency and trades-off in climate policy between *production intensive farming* (high GHG emissions from land used for farming with the diversion of remaining land to carbon sequestration activities) and *land intensive farming* (low GHG emissions from a land-extensive agricultural production system without the diversion of land to sequestration activities).

2. The basic problem

We consider a small country facing given world market prices. Agriculture can either be protected by tariffs (e.g., Norway), or have a liberal trade regime (e.g., New Zealand). In both cases we assume that a target has been established for the CO_2 equivalent of GHG emissions that the agricultural sector has to meet, either as a result of a national policy to reduce greenhouse gas emissions or as part of an international agreement. We examine two alternative instruments to achieve this target: a reduction in the prices of agricultural commodities or the use of a carbon tax. Price reduction can be achieved through cuts in tariffs (Norway), or by imposing a tax on agricultural commodities (New Zealand). In the case of a carbon tax we assume that this is levied on inputs that generate pollution (e.g., inorganic fertilizer).

2.1 The technical structure for production and emissions

The agricultural sector produces commodities by using land and other inputs, summarized by the production function:

$$(1) \qquad Y = Y(K,L) = K^{\alpha} L^{\beta}, \ \alpha + \beta < 1.$$

Y is (aggregate) production, *L* is land used in farming and *K* is other inputs, *hereafter referred to as capital*. Note that we assume that production exhibits decreasing return to scale.

While *L* is land used in farming, we can think of *K* as production factors that are used to generate agricultural output from the land, e.g., fertilizer and machinery used for tillage. The assumed Cobb-Douglas technology says that it is possible to substitute between *L* and *K*. In our case this means that land can replace fertilizer and tilling (and vice versa).[2]

The sector's emission of GHG, *E*, is specified through the functional relationship:

$$(2) \qquad E = E(K,L,Y) = K^{\rho} L^{-\zeta} Y^{\tau},$$

i.e. emissions are assumed to be dependent on the use of capital, farm land, and the size of production. Our motivation for (2) is as follows: In practice, the level of emissions depends on chosen production techniques. A technique that requires the use of pesticides pollutes more

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[2] The substitution possibilities are given by the elasticity of substitution. Since we have a Cobb-Douglas production technology this elasticity is unity.

than a technique that is free from pesticides. Since pesticides are part of *K,* the higher the use of *K,* ceteris paribus (given *L* and *Y*), the higher GHG emissions. The parameter ρ measures the strength of this effect. Use of land may have the opposite effect. For example, the use of synthetic fertilizers in grain production improves productivity, but also increases emissions. By substituting fertilizer for land grain production, emissions will be lower while keeping grain production unchanged. Consequently, with *K* and *Y* constant, an increase in *L* yields a decrease in *E*. The parameter ς measures the size of this effect. Lastly, the activity level of the sector matters. This level is measured by the aggregate production, and the emission effect by τ. The relationship (2) suppresses many relevant factors and is exceedingly simple. Nevertheless, it reflects basic factors that are relevant for the discussion of GHG emissions. In the following we strengthen this focus by further simplifying (2) to:

$$(3) \qquad E = E(K,L,Y) = (\frac{K}{L})^{\rho} Y ,$$

i.e. assuming $\rho = \varsigma$ and τ=1. In the later discussion ρ will be referred to as the coefficient representing the intensity of emissions. To sum up: if more land is used in farming, *Y* will increase. For this reason, pollution will also increase. We will refer to this as the *production effect*. On the other hand, (holding *K* constant), production becomes less capital intensive. This means that pollution will decrease. This will be referred to as the *intensity effect*.

In addition to use land in farming (*L*), land can be devoted to carbon sequestration activities (offsets), for example the planting of perennial grasses or trees. Formally, our assumption is:

$$\lambda(\overline{L} - L),$$

where λ is the sequestration coefficient per hectare. $\overline{L}$ is the available land and $(\overline{L} - L)$ is land used for sequestration activities.[3] Taking this into account, (3) changes to:

$$(4) \qquad E = E(K,L;\lambda) = (\frac{K}{L})^{\rho} K^{\alpha} L^{\beta} - \lambda(\overline{L} - L).$$

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[3] Land can simply be left idle and that may generate some carbon sequestration. That possibility is ignored and we assume that active sequestration uses for the land are required.

2.2 The efficiency problem

Let us first define the profit, π, of the agricultural sector:

$$(5) \qquad \pi = (p + s)Y - rK - wL + q(\overline{L} - L),$$

Here, p is the fixed world market price for farm output and s is the output subsidy (Norway). In addition, r and w are the user prices for capital and farm land respectively, and Y is given by (1). Furthermore, q is the per unit net profit from sequestration activities.

There is a restriction on available land:

$$(6) \qquad L \leq \overline{L}.$$

In our analysis, we assume that there is an agreement that CO_2 emissions shall not exceed a certain level denoted by $\overline{E}$, i.e.

$$(7) \qquad E \leq \overline{E},$$

where E is given by (4). If we look at current emission agreements, sequestration activities are not credited against the emissions generated by agricultural production; λ has therefore to be set to zero. The efficiency problem can now be stated as:

Maximize π in (5), subject to (1), (4), (6)-(7).

This problem does not have a unique solution. So, we solve the problem by either decreasing producer prices, p+s, or increasing input prices.

2.3 Solving the efficiency problem

In Figure 1, we illustrate the solution when there is no emission constraint, i.e. (7) is not taken into account. The optimal solution, called the base solution, is marked as point *1.* From Figure 1 we can read the optimal quantities of K and L, and the optimal output as Y_1 associated with the isoquant Y_1-Y_1. Note that we have assumed that in the optimal solution all available land is used for farming.

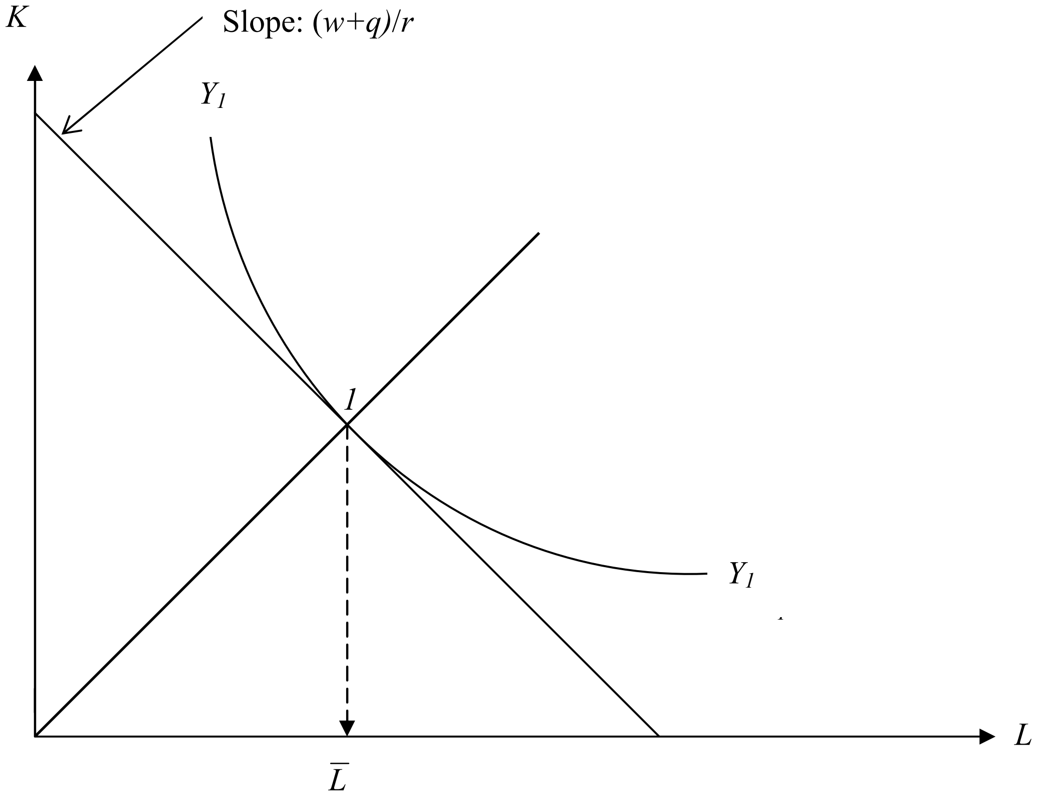

Figure 1: The base solution

We take it for granted that at point 1, emissions exceed the target $\overline{E}$. Next we take the emission constraint (7) into account. Assume first that we solve the problem by liberalizing trade, for example by reducing import tariffs. This means reducing producer prices. Since the production function is homothetic, and since relative input prices $(w+q)/r$ are kept constant, we move down the straight line ray through the origin in Figure 1. We continue the decrease in import tariffs until we have reached the emission target, $\overline{E}$, illustrated as point 2 in Figure 2. Optimal production given the new import tariffs is Y_2 associated with the isoquant Y_2-Y_2.

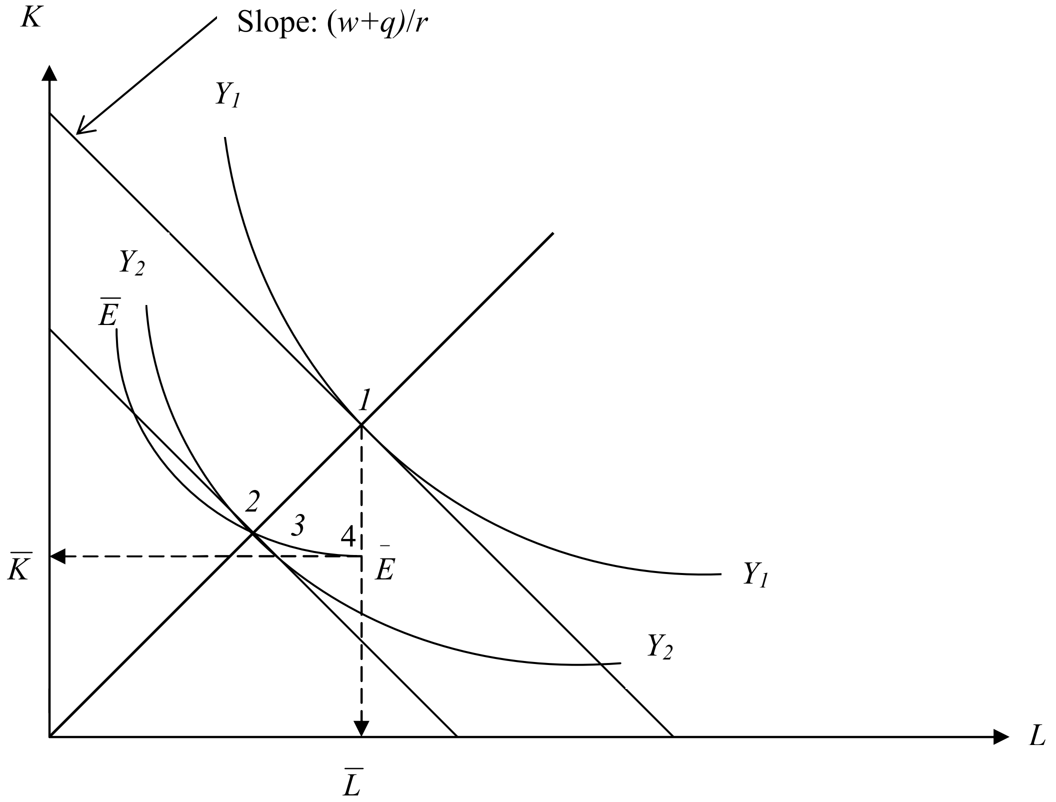

Figure 2: Achieving the emission target through trade liberalization or a carbon tax when the sequestration effect (λ) is weak or zero

The emission constraint

In Figure 2, we have also represented the emission constraint by the indifference curve, $\overline{E}-\overline{E}$. This is derived from (4), setting $E=\overline{E}$:

$$(8) \qquad \overline{E} = (\frac{K}{L})^{\rho} K^{\alpha} L^{\beta} - \lambda(\overline{L} - L),$$

which is a relationship in K and L. The sign of the slope of the $\overline{E}-\overline{E}$ curve can be derived by differentiating (8) with respect to L and K:

$$\frac{dK}{dL} = -\left(\frac{\beta-\rho}{\rho+\alpha}\right)\frac{K}{L} - \left(\left(\frac{K}{L}\right)^{-\rho} K^{1-\alpha} L^{-\beta}\right)(\frac{\lambda}{\rho+\alpha}) \quad .$$

We see that $\left(dK/_{dL}\right)<0$ if $\beta>\rho$, i.e. the distribution parameter for land is larger than the intensity coefficient. The sequestration parameter λ simply determines the steepness of the $\overline{E}-\overline{E}$ curve. In the extreme case of $\lambda=0$, we see that the curve is less steep than the Y_2-Y_2 curve[4], which is the case drawn into Figure 2. The same holds for small values of λ. Consider the point marked as 4. Here all land is used for agricultural production and the amount of capital used, $\overline{K}$, generates emissions equal to $\overline{E}$.

For larger values of λ, the $\overline{E}-\overline{E}$ curve becomes steeper than the Y_2-Y_2 curve, as shown in Figure 3. The emission curve, $\overline{E}-\overline{E}$, still goes through the "non-sequestration" point 4. Trade liberalization now gives a solution at point 5. We see that production now is at a higher level compared to the zero (or low) λ case, i.e. point 2.

Using a carbon tax to achieve the emission target

(i) Weak offsets (λ low or zero)

An alternative way to reduce pollution is through taxing inputs. In the case depicted in Figure 2 this means taxing capital. Relative factor prices will then change to the benefit of those generating lower emissions, so that the target on emissions can be met at lower costs through substitution. This means we can reach point 3 in Figure 2. Compared to point 2 this implies an increase in production.[5]

(ii) Strong offsets (λ high)

When λ is high, the $\overline{E}-\overline{E}$ curve is steeper than the isoquant. From Figure 3, we see that in this case the optimal point is to the north-west of point 5, marked as point 6. To reach this point land must be taxed. Consequently, for high λs factor intensity is reversed compared to the zero λ case. Again production is larger compared to the trade liberalization point 5.

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[4] The slope of the Y_2-Y_2 curve is $\frac{dK}{dL}=-\frac{\beta}{\alpha}\frac{K}{L}$.

[5] Production in point 3 will be lower than that in point 1. The reason is that, compared to point 1, ceteris paribus, the price of capital has increased. Since costs are higher, producers reduce the output of agricultural products.

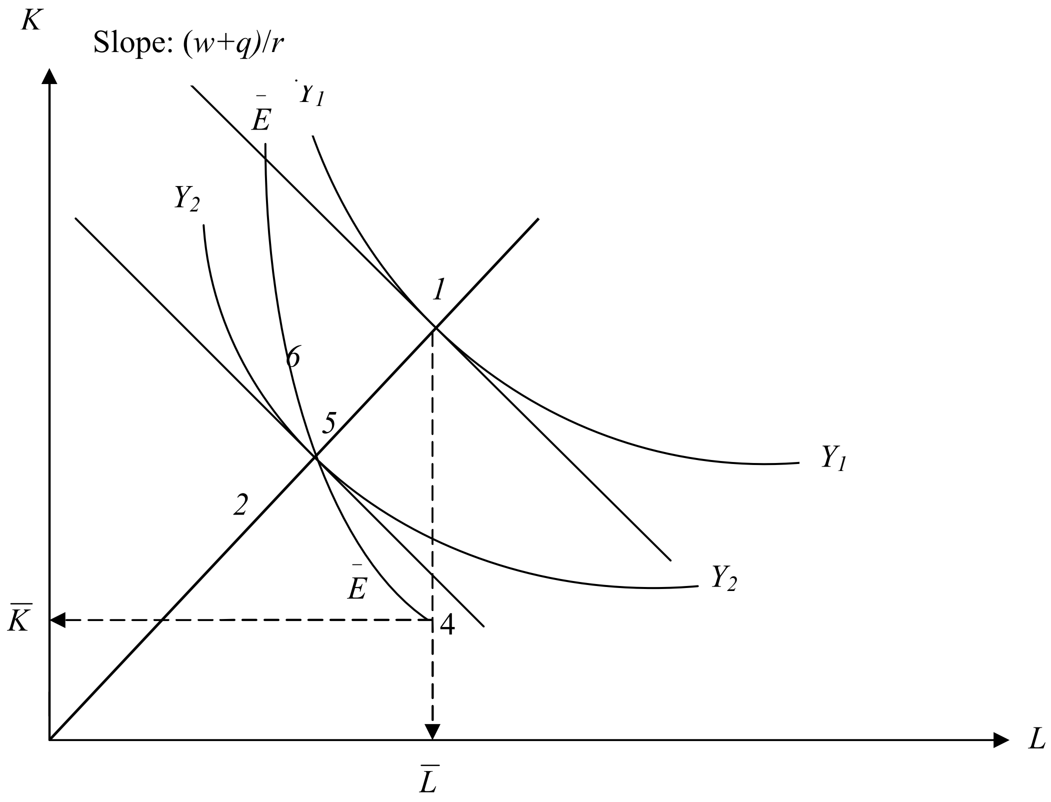

Figure 3: Achieving the emission target through trade liberalization or a carbon tax when the sequestration effect (λ) is large

3. The empirical model of Norwegian agriculture and the representation of GHG emissions

The tool that we use to examine empirically the issues set out in the previous section is a partial equilibrium model for the Norwegian agricultural sector: Jordmod. The model has been used earlier to analyse the provision of public goods by Norwegian agriculture (Brunstad et al. 1999 and 2005) and the effect of trade liberalization on the Norwegian agricultural sector (Blandford et al. 2010). A technical description of the model is given in Brunstad et al. (1995) and the latest version of the model is documented in Mittenzwei and Gaasland (2008). In the following we provide a brief overview of the model, with special emphasis on the treatment of GHG emissions.

Jordmod is a price-endogenous, partial equilibrium model of the type described in McCarl and Spreen (1980). For given technology and demand functions, domestic market clearing prices and quantities are computed. Prices of goods produced outside the agricultural sector or abroad are taken as given, and domestic and imported products are assumed to be perfect substitutes. As the model assumes full mobility of labour and capital, it should be interpreted as a long run model.

Domestic production takes place on “model farms” with fixed input and output coefficients.[6] The model farms span 11 representative farm types (e.g., combined milk and beef; grains), distributed over 32 production regions (with varying yields and limited supply of different grades of land), supplying 22 outputs (e.g., wheat; potatoes; cow milk; eggs) by means of 12 intermediate products (e.g., different grades of concentrated feed and roughage) and 25 other production factors (e.g., land, capital; labour, seeds; pesticides)[7]. The produce from the model farms go through processing plants before being offered on the market.

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[6] Although, inputs cannot substitute for each other at the farm level, due to the fixed coefficient assumption, there are substitution possibilities at the sector level. For example, beef can be produced using different technologies (model farms), both extensive and intensive production systems, and in combination with milk. Thus, in line with the general Leontief model in which more than one activity can be used to produce each good, the isoquant for each product is piecewise linear. Also, production can take place on small farms or larger more productive farms. Consequently, there is an element of economies of scale in the model.

[7] The model farms are optimized (in a separate module) for given prices, subsidy and tax rates, subject to functions for production technology (e.g., output and input coefficients per ha or per animal), and biological or natural restrictions. To increase the scope for substitution, model farms are constructed for different sets of relative prices (depending on specific scenarios). The data are based on extensive farm surveys carried out by the Norwegian Agricultural Economics Research Institute.

Functions and coefficients have been attached to activities and production factors in the model to reflect GHG emissions, based on the Intergovernmental Panel Climate Change (IPCC) methodology, adapted to Norwegian conditions and practices. Details, including parameters, data sources and implementation, are given in Gaasland and Glomsrød (2010), but a short overview is presented below.

Table 1. Sources of GHG emissions in Norwegian agriculture in CO_2 equivalent, mill. kg. and percentage of total (2005)

Enteric fermentation	1,917 (35%)
Manure management	1,108 (20%)
Fertilizer, manure	233 (4%)
Fertilizer, syntetic	576 (11%)
Net emmision land use	1,530 (28%)
Other	69 (2%)
Total GHG emissions	*5,433 (100%)*

The sources and the actual numbers of GHG emissions from Norwegian agriculture are given in Table 1. These are incorporated into the model. For milk cows, emissions from enteric fermentation are expressed as a function of the amount and mixture of feed, while for all other animals they are reflected by an animal-specific constant parameter per head. The amount of manure, which leads to emissions of methane and nitrous oxide through manure management, and nitrous oxide generated by the use of manure as fertilizer, is modelled as a function of fodder intake for milk cows and as an animal-specific constant for other animals. For manure management, the animal-specific emission parameters depend on the system applied. Constant parameters per hectare, which differ between the use of manure and synthetic fertilizer, represent emissions of nitrous oxide from organic and inorganic fertilizers. Net emissions from land use relate to carbon dioxide that is assumed to be released from tilled land (2,000 kg per hectare per year) adjusted for the small amount assumed to be sequestered on no-till land (about 100 kg per hectare per year). The ‘other’ category in Table 1 includes indirect emissions related to deposition of ammonia and leaching and runoff of nitrogen. Carbon dioxide released by the use of fossil fuel in agricultural activity (which amounts to 8 per cent of the agricultural emissions) is not included in the model. Emissions of all GHG types are translated into carbon dioxide equivalents.

4. Model analysis

As indicated above our analysis takes the perspective of a small country whose agriculture is currently protected and whose political aim is to keep agricultural activity as high as possible within the constraints imposed by multilateral agreements. The point of departure is existing policy, as generated by the model for the base year 2003. With respect to a potential new WTO trade agreement, we employ the Falconer proposal of December 2008 (WTO, 2008). No similar global climate policy proposal or commitment exists. However, prior to the Copenhagen climate conference, Norway proposed a reduction in economy-wide emissions of 30 per cent by 2020 (compared to the 1990 level). In our analysis we assume that agriculture has to reduce its GHG emissions by that percentage.

4.1 Current situation

The model's representation of agricultural policy in the base year 2003 is reported in column 1 of Table 2. Since the production of agricultural commodities, as well as agricultural support, has been relatively stable over the last decade, the base year 2003 is representative of the Norwegian support regime. In what follows, we emphasize current status with respect to trade liberalization and GHG emissions.

Norwegian agriculture, which accounts for less than one per cent of GDP and three per cent of domestic employment, is among the most heavily protected in the world (NILF, 2007).[8] As noted earlier, the OECD's Producer Support Estimate (PSE) for Norway was 66 per cent in 2009, the highest among the Organization's member countries (OECD, 2010). The total agricultural support generated by the model is NOK 20.1 billion (1 NOK ≈ 0.125 €), of which NOK 11.8 billion is various forms of budget support and NOK 8.6 billion is market price support buttressed by import tariffs for major products in the range of 190-430 per cent.[9] Market price support and output subsidies constitute 60 per cent of the total support. (These numbers are not reported in Table 2).

The first column in Table 2 shows that Norway exceeds the proposed Doha commitment on the Total Aggregate Measurement of Support (TAMS) by 102 per cent, Blue Box commitment by 111 per cent and the Overall Trade Distorting Support (OTDS) by 95 per cent.

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[8] In spite of climatic disadvantage, Norway is self-sufficient in the main temperate zone products, with the exception of grain. 10 per cent of the milk production is exported in the form of cheese, by means of export subsidies.

[9] By comparison, the actual producer subsidy estimate (PSE) reported by OECD for 2003 is NOK 21.7 billion, of which NOK 12.5 billion is budget support and NOK 9.2 billion is market price support.

Consequently, Norway is far from free trade in agriculture, and the sector would apparently be severely affected by extensive trade liberalization.

As noted earlier, even through agriculture accounts for a small share of Norway's GDP, it contributes a significant share of the country's total GHG emissions. Table 1 shows how these emissions are distributed across various sources. Enteric fermentation accounts for more than 1/3 of total agricultural emissions. This source is closely related to the number of ruminants (i.e., dairy cows, heifers, beef cows, sheep and goats), which are the basis of most agricultural activity in Norway's rural areas. Net emissions from agricultural land are the second largest category. Intensive soil tilling contributes to high emissions from agricultural land. Almost 90 per cent of the land is regularly tilled, i.e., land with permanent cover is scarce. 20 per cent of the emissions come from manure management, which is also correlated with the number of animals, inclusive of pigs, poultry and hens. Roughly 15 per cent of total emissions are associated with the use of fertilizer (organic and inorganic). Intensive soil tilling and use of fertilizer are a ways to compensate for climatically-induced low yields and a short growing season. GHG taxes or regulations have so far not been imposed on Norwegian agriculture.

Table 2. Trade liberalization versus a carbon tax – results of model simulations

	Base solution	**Doha solution**	**Further trade liberalization**		**Carbon tax**	
			No offset	Offset	No offset	Offset
Production (index; base solution = 100)	100	96	78	89	81	98
(share of production from ruminants)	(0.54)	(0.53)	(0.53)	(0.53)	(0.52)	(0.52)
Land use (base solution = 100)	100	97	69	88	70	79
(share of agricultural land that is tilled)	(0.87)	(0.87)	(0.88)	(0.87)	(0.82)	(0.92)
(kg nitrogen per ha; wheat/grass)	(155/194)	(155/192)	(155/188)	(155/192)	(141/186)	(151/232)
Measured agricultural support (base solution = 100)	100	94	75	85	73	98
Economic welfare (NOK billion)	18.7	21.4	26.5	22.9	26.0	23.1
Trade liberalization effects (Doha ceilings = 100)						
TAMS	202	62	6	25	2	94
Blue box	211	100	89	99	87	100
OTDS	195	73	36	51	33	91
GHG emissions (base solution = 100)	100	99	70	70	70	49
GHG emissions per hectare (ton CO_2 equiv. per ha in ag. activity)	(6.02)	(6.16)	(6.10)	(6.02)	(5.96)	(6.46)

4.2 Doha solution

One of the major aims of the on-going Doha Development Round is to reduce agricultural protection and to impose greater discipline on domestic agricultural subsidies, particularly those that are most trade distorting. The latest proposal for support reduction commitments was prepared by the previous chair of the WTO agriculture committee, Crawford Falconer (WTO, 2008). As already noted, for Norway the proposal restricts support in the main categories (TAMS, blue box and OTDS) to roughly one-half of recent levels. In addition, there are separate commitments with respect to specific policy instruments, e.g., export subsidies are to be eliminated and market access improved through reductions in tariffs and increases in tariff rate quotas (TRQs).

The impact of this proposal on Norwegian agriculture has been analysed by Blandford et al. (2010). Column 2 in Table 2 shows the main results, including the implied impact on GHG emissions. Contrary to elevated expectations by the substantial cuts in the various categories of support, we see that the commitments can be met with only modest impacts on agricultural production, land use, and economic support. The reported 4 per cent decrease in production and 3 per cent decrease in land use can mainly be explained by the elimination of subsidised exports. Consequently, GHG emissions are virtually unaffected.

These small impacts are due to the fact that the proposed Doha disciplines are weak with respect to trade-distorting support (Orden et al., 2011). As explained in Blandford et al. (2010), there are important loopholes that can be exploited to avoid real changes in policies. In anticipation of a future agreement, Norway has already adopted or signalled future strategic adjustments designed to minimize the impact of a new WTO agreement on its agricultural policy. The notified TAMS and blue box support have been reduced simply by shifting support to the green box without major changes in policy. Furthermore, there are generous possibilities for defining sensitive products that are exempt from harsh cuts in import barriers. Most important, the market price component of the TAMS can be reduced by abolishing administered prices for selected products while maintaining real market price support through market access restrictions. There is also substantial flexibility for compensating producers through deficiency payments within the TAMS ceiling.

4.3 Further trade liberalization

Compared to the Doha proposal, more effective trade liberalization would be required if production is to change sufficiently to meet the GHG emission target. In this section we assume that farmers are confronted by the full effect of the elimination of export subsidies and expanded market access commitments at current subsidy rates. Import tariffs are reduced (proportionally) until the 30 per cent emission target is met. With reference to Figure 2, we move along the ray from point 1 and south-west to point 2 (no carbon offset) or point 5 in Figure 3 (carbon offset), respectively. As the results in column 3 and column 4 in Table 2 show, the emission target is binding while the Doha trade commitments are met with a safe margin.

Agricultural activity is now more seriously affected. When carbon offsets are not allowed, production and land use decrease by 22 per cent and 31 per cent, respectively, compared to the current situation. If carbon offsets are allowed, production and land use are reduced by 11-12 per cent, i.e., agricultural activity can be kept at a higher level. As a consequence of trade liberalization and lower agricultural activity, agricultural support falls (by 25 per cent in the no-offset case), and this contribute to increased economic welfare (NOK 7.8 billion). For a high cost country like Norway, this indicates that GHG abatement cost is negative in the sector if no value is attributed to agricultural activity beyond that determined by the world market price of food.

While the intensity in production relevant to emissions was represented by the capital/land ratio in the simple analysis in Section 2, the model provides other and more specific indicators, such as: (1) the share of production attributed to ruminants (ruminants cause high emissions per unit of production); (2) the share of land used in agricultural production that is regularly tilled (tillage emits carbon); and (3) the use of nitrogen per unit of land (emissions increase with the use of fertilizer). An aggregate indicator that incorporates these specific indicators is GHG emissions per hectare from agricultural production.

Based on these indicators, it can be seen that intensity in production is more or less unchanged compared to the base solution. The reason is that the abatement strategy used in this simulation involves no major change in relative prices for production factors, but is merely based on a cut in producer prices. Consequently, substitution between low and high emission activities is more or less ruled out.

4.4 Carbon tax

A more targeted policy to reduce GHG emissions would involve an explicit tax on such emissions or an implicit tax generated by a cap-and-trade scheme with a binding cap on total emissions. These options, in contrast to the trade liberalization scenarios, will affect relative factor prices. With the base solution as a point of departure, we introduce a tax of NOK 300 (roughly €38 at current exchange rates) per ton of GHG emissions (CO_2 equivalent). Also, to comply with the anticipated Doha agreement, we implement the specific export subsidy and market access commitments. Under these conditions, GHG emissions will, according to the model simulation, be below the emission ceiling. Consistent with the assumption that the authorities have a preference for maintaining a high level of agricultural activity, we scale up production proportionally until the emission target becomes binding.

Compared to the trade liberalization case, we see that production is higher than in the corresponding trade liberalization scenarios. In the no-offset case production increases from 78 to 81 per cent of the recent level. The anticipated substitution towards less emission-intensive activities also takes place in the no-offset case. Mainly as a result of reduced tillage and less use of fertilizer, emissions per hectare decrease by roughly 2 per cent. Although the effects are modest, the qualitative results conform to the situation set out in Figure 2 in terms of a movement from point 2 towards point 3.

When carbon offsets can be credited to agriculture's GHG account, the Doha trade agreement becomes binding rather than the GHG target. Aggregate production is maintained close to the present level, while emissions are reduced by about 40 per cent. Furthermore, factor intensity is reversed in the sense that less land is used per unit of output. With reference to Figure 3, this is analogous to a movement from point 5 towards point 6. GHG emissions per hectare increase by roughly 7 per cent as the soil is tilled more intensively.

An important conclusion derived from these results is that when agricultural land can be used for significant carbon sequestration activities (i.e., the offset parameter λ is high) and when the resulting carbon offset can be credited to agriculture's GHG emissions account, there may be a strong tendency to intensify agricultural production, even if this leads to higher emissions from agricultural production *per se*.

5. Conclusion

In this paper we have dealt with strategies for complying with trade liberalization and GHG emission cuts from the perspective of a small country whose agriculture is currently protected and whose political aim is to keep agricultural activity as high as possible within the constraints imposed by multilateral agreements.

We demonstrate that trade liberalization implied by the Doha draft agreement on agriculture will not have a major impact on either Norwegian agricultural production or emissions; i.e., the proposed 30 per cent cut in GHG emissions will not be achieved. Consequently, more effective trade liberalization or carbon taxes are required. While both of these measures will reduce agricultural activity (trade liberalization more than carbon taxes), economic welfare increases. For a high cost country like Norway, this indicates that GHG abatement cost is negative in the sector if no value is attributed to agricultural activity beyond that determined by the world market price of food.

The analysis shows, as a main result, that the impacts on agricultural activity of the proposed emission cut depend substantially on whether credits are allowed for carbon sequestration (carbon offsets) on land taken out of agricultural production. According to the model simulations, aggregate production can be kept 15-20 per cent higher when carbon offsets are credited. Furthermore, while a carbon tax in the no-offset case provides incentives to substitute towards less emission-intensive activities, factor intensity is, in the offset case, reversed in the sense that emissions per unit of land increase. The intuition of this result is that production factors that increase land productivity (e.g., fertilizer and tillage) also tend to increase emissions per land unit, so that an intensification of production (less land per produced unit) may release land for offset activities. A more general conclusion revealed by these results is that when agricultural land can be used for carbon sequestration activities and when the resulting carbon offset can be credited to agriculture's GHG emissions account, there may be a strong tendency to intensify agricultural production, even if this leads to higher emissions from agricultural production *per se*.

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