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Can a Warmer Climate Save Northern Agriculture?

by

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Agriculture at high latitudes is expected to be the main beneficiary of a man-made climate change. A numerical model, using Norway as a case, is employed to analyze the impacts of a warmer climate on northern agriculture. The computations indicate that the current degree of self-sufficiency can be achieved with 15% less budget support and higher economic welfare. However, it may be argued that environmental goods, such as landscape and biodiversity preservation, and settlement, are more important than self-sufficiency for northern agriculture. It is demonstrated that, in that case, welfare gains are substantially lower, and can even be negative.

Key words: climate change, northern agriculture, environmental goods, numerical model

Introduction

At high latitudes (above 60º N) in northern regions,[1] temperature is frequently the limiting factor for crop growth. In Norway, for example, most production is restricted to pasture and forage grasses, potatoes and vegetables, grain for feed, and some spring wheat for human consumption. Furthermore, yields per hectare are low. On average, wheat and potato yields are about 60% of the yields in central Europe.[2]

To achieve ambitious political targets with regard to production, land use and agricultural employment, it is common practice to compensate for climatic disadvantage through substantial subsidies and import barriers. For Norway and Iceland, respectively, total support in 2002 amounted to 71% and 63% of the total value of production in agriculture (OECD 2003). Prior to membership of the European Union, the figures were 67% and 51% for Finland and Sweden, respectively, whereas the OECD average is currently about 30%.

The high level of subsidy is an obvious economic burden for these countries. The subsidies must be financed by more or less distorting taxes that discriminate against other sectors in the economy. In addition, high prices on food because of import barriers impair the consumers' purchasing power. Yet, the main threat to the farmers in these regions is the ongoing international pressure, directed by the World Trade Organization (WTO), to reduce subsidies and import barriers. In the WTO negotiations, special emphasis is put on trade distorting measures such as deficiency payments, import tariffs and export subsidies, whereas production neutral support and measures related to environmental and public goods in agriculture are more acceptable.

Northern agriculture, as in Norway, is thus squeezed from many directions. Is it possible, then, that a warmer climate, arising from the greenhouse effect, can save it? Most studies of this issue predict high-latitude regions to be the beneficiaries of a climate change.

This basic question will be analyzed in this paper by using numerical models as a tool and Norwegian agriculture as a case.

Most studies on the economic impacts of climate change focus on production efficiency, i.e., effects on yields and factor use (e.g., land, labor, capital and pesticides), and how it affects producers, consumers and taxpayers in different regions, when adaptation possibilities are taken into consideration.[3] In northern regions however, production efficiency is a questionable target. Even when taking into account climate change, agriculture in these regions will, in general, not be competitive. Arguably, more valid areas for support are environmental and public goods, as represented by landscape and biodiversity preservation and settlement issues (Brunstad et al. 1999). Arguments for public goods are more likely to conform to the WTO principles.

The main contribution of this paper is to demonstrate that, when public goods are emphasized rather than production, the economic welfare gains from a warmer climate will be substantially lower, and may even be negative.

First, the present conditions for agriculture in Norway are described, and predictions for the future climate until 2050 in differing parts of Norway are reviewed, with consideration given to the temperature, length of growing season, precipitation and atmospheric carbon dioxide (CO_2) concentration. On this basis, the effects on the yield of different plants in various regions of Norway are estimated. Then, a stylized model is applied to demonstrate that the welfare gains of a warmer climate crucially depend on political targets. Later, to obtain more disaggregated results, a price endogenous sector model of Norwegian agriculture is employed. This model is adjusted for the estimated change in productivity and costs by introducing eight climate zones in each of the model's nine production regions. The model is developed for policy analyses, and provides a consistent framework for dealing with the coherence between different elements of the agricultural sector.

Climate and yields

This section describes the present conditions for agriculture in Norway. The country can be divided into nine production regions on the basis of climatic and topographic conditions (see Table 1). Furthermore, the acreage in each region can span several climate zones, from 1 (warmest) to 8 (coldest).

The classification of climate zones follows NILF (1990), and it is based on a time series of monthly mean temperatures in April and July. As Figure 1 shows, each zone is delimited by two curves similar to isoquants. Zone 4, for example, spans from point (April 3°C, July 16°C) to point (April 4°C, July 17°C), i.e., an interval of 1°C. The shape of the curves indicates that there is a trade off between low temperatures in April and high temperatures in July, and vice versa; however, in most regions, these temperatures are positively correlated. Zone 4 corresponds to the climate in south-east Norway, and zones 1 and 2 match the climate in central Europe, e.g., Copenhagen (zone 2) and Paris (zone 1). Yields per hectare for important Norwegian crops vary between climate zones, as seen in Table 2.

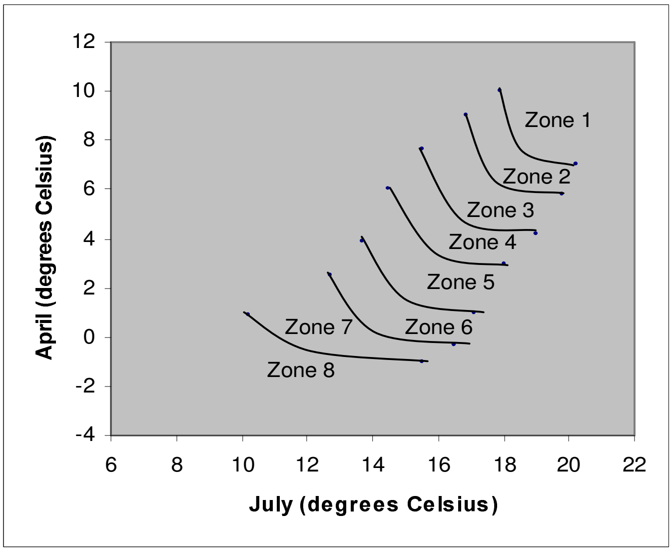

Figure 1. Classification of climate zones (Source: NILF 1990, p. 19)

Table 1 shows that the agricultural land in Norway amounts to nearly 1 million hectares,[4] of which two thirds are in climate zones 4 and 5. The yield of wheat, for example, is 4000 kg per hectare in zone 4 (see Table 2), or about 70% of the level in central parts of Europe (zone 1). The three coldest zones, where grain for consumption is ruled out, constitutes one fifth of the agricultural area. Only one tenth of useful land lies in zone 3, and there is no land in zones 1 and 2.

Table 1. The Norwegian acreage distributed in regions and climate zones (100 hectares)

	Regions									
Climate zone	North	Middle - lowland	Middle - hilly	West	South-west	South	South-east-lowland	South - east-hilly	South-east-highland	**Total (share in parenthesis)**
1										
2										
3						202	769	283		1254 (0.12)
4		336	21	646	211	90	2176	309		3789 (0.38)
5	193	624	268	915	197	95		264	405	2961 (0.30)
6	285		181	196		17			206	885 (0.09)
7	321		109			14			327	771 (0.08)
8	61		21						186	268 (0.03)
Total	860	960	600	1757	408	418	2945	856	1124	9928 (1.00)

Source: Based on NILF (1990)

The warmest and driest climate is in the south and south-east, where most of the grain production takes place. The regions of the west and south-west have the most rainfall and a relatively mild climate, and are suited for forage grasses and pastures. The coldest regions are in the north and in the abundant highland. Topographically, conditions are best for agriculture in the lowland of the eastern and middle regions, as well as in the south-west. Altogether, more than 40% of the total agricultural land is located in these regions.

The length of the growing season[5] (GS) and the growing degree-days[6] (GDD) give additional information about the climatic conditions for agriculture. For most crops, a longer GS will be beneficial as the temperature will increase during periods presently experiencing sub-optimal temperatures.[7] There is also the potential to utilize species with higher yields, e.g., to switch from spring to winter wheat. GDD is an estimate of accumulated heat, and is therefore a useful index of the energy available for biological growth.

Table 2. Yield per hectare for various crops in different climate zones[1)] (in parenthesis, relative to zone 4)

Climate Zone	Forage grasses (perennial) Kg of dry matter		Potatoes Kg		Grain for feed (barley) Kg (15% water)		Grain for consumption (wheat) Kg (15% water)	
1	12500	(1.19)	34000	(1.31)	5250	(1.50)	5750	(1.44)
2	12000	(1.14)	32000	(1.23)	4250	(1.21)	5400	(1.35)
3	11500	(1.10)	29000	(1.12)	4000	(1.14)	4750	(1.19)
4	10500	(1)	26000	(1)	3500	(1)	4000	(1)
5	9000	(0.86)	23000	(0.89)	3000	(0.86)		
6	7500	(0.71)	20000	(0.77)	2500	(0.71)		
7	6000	(0.57)	17000	(0.65)				
8	4500	(0.43)	14000	(0.54)				

[1)] Potential yields assuming sufficient supply of water and nutrition, the present level of atmospheric CO_2 concentrations, and the present method of cultivation.
Source: NILF (1990).

Skaugen and Tveito (2002) have estimated the "normal" GS and GDD on the basis of a time series (1961–1990). GS varies from less than 50 days to 200 days. Parts of the north and the high mountain areas have the shortest GS (0–25 days). In the southern coastal lowland the GS is 150–200 days. GDD varies, in the normal period, from less than 200°C to more than 1200°C.

Consideration is now given to predictions about future climate (see Table 3) and the presumed effects on yields of different crops and regions. According to the regional climate change scenario for Norway for the period 2030–2050 (RegClim), the temperature is assumed to increase 1.2°C on average, with the greatest increment occurring in winter, and the smallest rise in spring and summer. There are regional variations, with the increase predicted to be especially high in the north, and for the inland areas to be higher than at the coast.

Table 3. Predicted change in climate from the period (1980–2000) to (2030–2050)

	Region			
	North	West	South and south-east	Norway (in aggregate)
Average change in temperature[1] (°C)				
Spring (March–May)	1.4	0.9	1.0	1.1
Summer (June–August)	1.2	0.7	0.6	0.9
Autumn (September–November)	1.7	1.1	1.3	1.4
Winter (December–February)	2.0	1.2	1.3	1.6
Year	1.6	1.0	1.1	1.2
Average change in precipitation[1] (mm per day and night, and %)				
Spring	0.2 (5.0%)	0.1 (1.2%)	–0.1 (-4.1%)	0.0 (0.1%)
Summer	0.1 (1.5%)	1.0 (18.2%)	0.1 (1.7%)	0.4 (9.5%)
Autumn	0.8 (18.2%)	1.5 (23.5%)	0.3 (6.9%)	0.9 (17.1%)
Winter	0.2 (5.2%)	0.6 (9.3%)	0.4 (13.1%)	0.4 (9.4%)
Year	0.3 (7.8%)	0.8 (13.5%)	0.2 (4.3%)	0.4 (9.6%)
Increase in				
GS[2]	30–87 days[4]	30–87 days	20–30 days[5]	
GDD[2]	30–100%	30–100%	<30%	
Increase in CO_2 concentrations[3]				100%

1) Source: RegClim (see http://regclim.met.no)

2) Source: Skaugen and Tveito (2002).

3) Source: Houghton et al. (2001).

4) In the north-eastern parts of this region (Finnmarksvidda), the increase in GS is predicted to be below 20 days.

5) In the most fertile areas in south-east and the middle regions of Norway, GS is predicted to increase by less than 20 days.

Precipitation is expected to rise in most places, especially in the west where it is already abundant, and in the autumn. In spring, the rainfall may decrease in the south-eastern regions. The growing season is estimated to extend by 30–87 days in most areas, except for the south-east where the increase is expected to be substantially less. Finally, the atmospheric concentrations of CO_2 (carbon dioxide) are expected to double within the next century (Houghton et al. 2001).

The question is: how will the climate change affect the yields of different crops and regions? Crop yield is a complex function of many related variables, including temperature, length of growing season, moisture availability, CO_2 concentration in the air, solar radiation, topography, soil, cultivation methods, and the incidence of pests and diseases. Understandably, yield is not a linear function of these variables, and greatly depends upon the prevailing growing conditions. Furthermore, the functional relationship depends on the specific plant.

In Norway, temperature is the dominant limiting factor for crop growth. As shown in Table 2, there is considerable potential for higher yields if the temperature increases. The effect is especially high for countries such as Norway in cold climate zones, as the yield normally increases with temperature at a decreasing rate. For terminate crops, such as grain, temperatures above the zone 1 level may have a negative effect on yields because of hastened maturation (Parry 1990). This is seldom the case for determinate plants, such as forage grasses, which continue to grow and yield all seasons.

The predicted rise in temperature suggests a one-level jump in climate zone rank for most Norwegian regions, which, *ceteris paribus*, will enhance wheat yields by 14% in the best lowland of the south-east, partly because it will be possible to switch from spring to winter wheat with the extended GS. The yields of forage grasses and potatoes are expected to increase by 10–25%, depending on the prevailing zone (see Table 2).[8]

The temperature–yield estimates assume a sufficient supply of water and the current ambient CO_2 concentration. In general, Norwegian agriculture suffers a precipitation deficit in May, June and the beginning of July, and has a surplus in the autumn. The change in climate may affect water availability in different ways. First, higher temperatures lead to higher rates of evaporation[9] and consequently reduced moisture availability. However, an increased CO_2 level will tend to improve water use efficiency by reducing transpiration.[10] Furthermore, rainfall is predicted to increase, especially in the autumn, but also in summer. In spring, only a minor change in rainfall is expected.

It is hard to say, based on these contrary effects, how water availability will be affected in the beginning of the growing season (May–June). In the autumn, it is likely that the prevailing water surplus will increase in the west and north. This may, however, be partially offset by more seasonal flexibility because of a longer growing season.

It is generally agreed that an elevated atmospheric CO_2 concentration would be beneficial for crop growth because of an increased photosynthetic rate and that C_3 plants (e.g., wheat, barley, potato, clover, soybean and rice) will be more responsive than C_4 plants (e.g., maize, sugarcane and sorghum). However, the magnitude of enhanced growth, especially when temperature and rainfall also change, is more uncertain.

Nevertheless, a review of results from Free-Air CO_2 Enrichment (FACE) experiments,[11] conducted by Kimball et al. (2002), indicates that, when the CO_2 level doubles, wheat yields rise by an average of 18%, given ample water and nitrogen, whereas potato and clover yields gain 42% and 36%, respectively. Note that all the important Norwegian plants are C_3 species, and thereby are relatively responsive to a CO_2 enrichment.

How political targets affect the welfare gains

To demonstrate how the welfare gains of a warmer climate depend on political targets, a highly aggregated and stylized numerical model is applied. The model includes production sectors for agriculture, food processing and the rest of the economy. On the demand side there is a representative household that consumes three consumption goods from each of the production sectors. A public sector collects taxes and levies and disburses subsidies and transfers. The public budget is balanced by the endogenous level of transfers from the public sector to the private household. The trade balance is fixed to the base year level, and the model has an endogenous rate of exchange.

A consistent social accounting matrix using National Account Data for 1997 is presented in Table 4. A positive entry signifies revenue, and a negative number is expenditure. Observe that all row and column sums are zeros, which means that: I) supply equals demand for all commodities, II) no production sector has extraordinary profit, and III) the households exhaust all their revenues on consumption, saving and transfers.

The agricultural sector is modeled by a two level Constant Elasticity of Substitution (CES) production function:

$$y = [\alpha_1 q^{\rho_y} + \alpha_2 z^{\rho_y}]^{1/\rho_y}, \qquad (1)$$

$$q = [\beta_1 A^{\rho_q} + \beta_2 L^{\rho_q}]^{1/\rho_q}, \qquad (2)$$

$$z = [\delta_1 C^{\rho_z} + \delta_2 G^{\rho_z}]^{1/\rho_z}, \qquad (3)$$

where y is production, q is a CES composite of acreage (A) and labor (L) and z is an aggregate of capital (C) and other goods (G). α_i, β_j and δ_k ($\forall$ i, j, k = 1, 2) are distribution parameters. $\rho \leq 1$ ($\rho \neq 0$) is the substitution parameter, defined as $\rho = (\sigma - 1)/\sigma$, where σ is the constant elasticity of substitution between the inputs.

Table 4. Social accounting matrix for Norway (1997) (million NOK)

	Production sectors			**Trade**		**Household sectors**		
	Agriculture	Food processing	Other	Import	Export	Private household	Public sector	**TOTAL**
Agricultural goods	21 355	–14 977	–3 485	1 615	–580	–4 457	529	0
Processed food		34 189	–5 106	5 311	–2 035	–33 089	730	0
Other goods	–12 363	–7 506	1 020 291	374 398	–445 466	–397 813	–531 541	0
Labor	–9 466	–6 890	–446 661			463 017		0
Capital	–8 663	–3 038	–396 800				408 501	0
Land	–180		–9 820				10 000	0
Net subsidies	9 317	–1 778	–158 419	–15 175		–59 718	225 773	0
Foreign currency				–366 149	448 081		–81 932	0
Transfers						32060	–32 060	0
TOTAL	0	0	0	0	0	0	0	0

The distribution parameters are calibrated from the cost shares that follow from the benchmark solution in Table 4. The substitution parameters are free parameters that depend on the technology. This point is emphasized in Figure 2, where the function is sketched and substitution parameters added.

In the figure, a low value is assumed for the first level substitution parameter ($\sigma_y = 0.1$). This implies that land and labor may, only to a minor degree, be substituted for by capital and other goods. At the second level, it is assumed that land and labor are used in fixed proportions ($\sigma_q = 0$), but that capital and other goods can replace each other more easily ($\sigma_z = 1$).

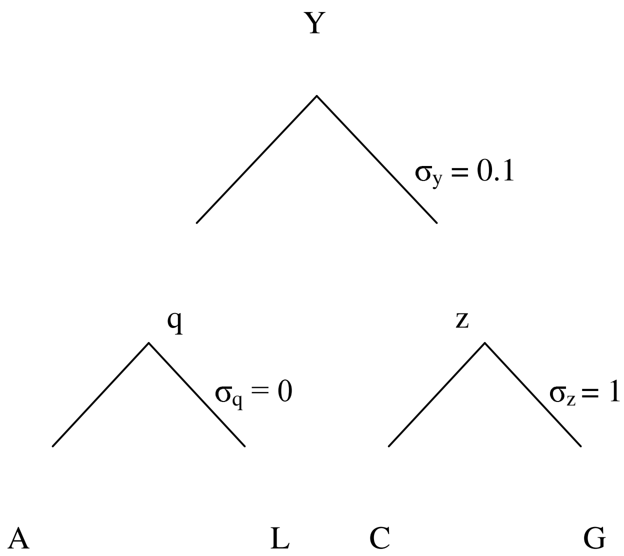

Figure 2. Two level CES production function in agriculture

This model formulation allows the highlighting of important economic mechanisms that are decisive in determining the welfare effects of a climate change. First, different objectives of the agricultural policy can be specified, either tied to the production level (Y), or to the use of factors such as acreage (A) or rural employment (L), where the latter is related to the so-called multifunctional role of agriculture. Second, sensitivity analyses can be performed with differing values placed on important parameters. Primarily, this concerns the substitution parameters that decide how easily the factors of production can replace each other as relative prices change.

The simulations are considered as follows. As an illustration, it can be assumed that climate change increases factor productivity by 30%. Two policy scenarios are considered. I) Production efficiency: producer's and consumer's surplus are maximized, given the benchmark support rates. II) The multifunctionality aspect: agriculture is to supply public goods such as landscape preservation and rural employment. As a proxy, it is taken that the use of acreage and man-years in agriculture must exceed the benchmark levels.

Alternative substitution parameters in production are considered. In the low flexibility case, the Hicks–Allen partial elasticity of substitution between factors in different nests is 0.1, whereas it is 1 between C and G. In the high flexibility case, these elasticities are 1 and 2. A and L are used in fixed proportions in both cases.[12] For demand, the Cournot own-price elasticity for food is assumed to be –0.5, i.e., demand is inelastic in price.

Table 5. Model results

	Production efficiency		Multifunctionality	
	Low flexibility	High flexibility	Low flexibility	High flexibility
Production level (baseline = 1)				
Agriculture	1.115	1.115	1.206	1.139
Food processing	1.066	1.066	1.102	1.076
Other	1.004	1.004	1.003	1.003
Price indices (baseline = 1)				
Consumer price index (numerairè)	1	1	1	1
Agricultural products	0.777	0.777	0.625	0.732
Processed food	0.908	0.908	0.845	0.889
Other goods	1.010	1.010	1.017	1.012
Labor	1.011	1.011	1.021	1.016
Capital	1.011	1.011	1.018	1.011
Acreage	1.011	1.011	1.019	1.014
Real exchange rate	1.010	1.010	1.017	1.012
Use of factors in agriculture (baseline = 1)				
Acreage	0.858	0.858	1	1
Labor	0.858	0.858	1	1
Capital	0.858	0.858	0.907	0.825
Other goods	0.858	0.858	0.908	0.825
Change in real income (billion NOK)	8.403	8.403	7.003	7.883

The results are seen in Table 5. Note that the increase in welfare, measured as real income, is higher for production efficiency than for multifunctionality. The explanation is as follows. When considering production efficiency, the focus is on the factor productivity that has increased as a result of a better climate. Greater production is thus achievable at lower costs. However, with regard to multifunctionality, increased factor productivity results in sub-optimal levels of land and agricultural employment, which must be compensated for by extra subsidies to these factors.

When the levels of land use and employment are raised, other inputs, such as capital and goods as well as production, increase, because inputs depend on each other to a variable degree. This side effect is especially raised if inputs are used in more or less fixed proportions, as is illustrated in the low flexibility case. In the high flexibility case, however, the desired land use and employment can be achieved at lower costs since capital and goods can be substituted by acreage and labor, and production can be held at a lower level.

Impacts and adaptations—disaggregated results from a sector model

Method and data

To obtain more realistic and disaggregated results, a price-endogenous numerical sector model of Norwegian agriculture (Gaasland et al. 2001a) is employed. The model is developed for policy analyses and provides a consistent framework for dealing with the coherence between different elements of the agricultural sector. For example, the consequences for different groups (producers, consumers and taxpayers), regions and agricultural techniques can be analyzed under alternative policy objectives or framework conditions.

For given input costs, demand functions and support systems, the model computes market clearing prices and quantities. The model reports figures such as production, use of inputs, domestic consumption and prices, import and export support, and economic surplus measured as the sum of producer's and consumer's surplus. On the supply side, the model has about 1000 model farms, each with fixed coefficients (Leontief technology), covering 19 different production activities on six scales in nine regions. The regional division reflects differences in climatic conditions, support systems and available land.

To analyze impacts of climate change and possible adaptations, important adjustments in the model have been made. First, the acreage in each of the nine production regions has been divided into eight climate zones (see Table 1). Second, to take account of topographical restrictions for grain production, the acreage has been divided into two categories. In the west, for example, the land is generally too steep or is too scattered for efficient grain production, irrespective of the climate. In the lowland of the south-east, however, most ground is suitable for grain production.

The yields in the different climate zones, reported in Table 2, are potential yields given sufficient supplies of water and nutrition, average soil quality and present methods of cultivation. Variations in precipitation, soil quality and topography imply that yields for identical crops in the same climate zone may vary regionally. To correct for this, regionally specific yields in the different climate zones must be deduced.

The procedure is as follows. Average yields for different crops in each region are known (see Table 6). Since the distribution of the acreage in climate zones is also known (see Table 1), together with the relative differences in yields between zones (see Table 2), it is easy to find the regional specific yields for each zone that correspond to the average yield.[13]

Table 6. Average crop yields in different regions (kg per hectare)

	North	Middle lowland	Middle hilly	West	South-west	South	South-east lowland	South-east hilly	South-east highland	Norway
Forage grasses*)	3550	4050	4460	3930	5980	4800	5240	4150	3990	4270
Grain, feed	1500	3640	3320	3110	4720	3050	4320	4150	3890	4140
Grain, consumption							4960	4310		4870
Potatoes	12570	20360	17340	18180	25850	19210	22890	21990	17850	21670

*) Feed unit per hectare. 1 kg dry matter is 0.6–0.7 feed units.

The original model farms are based on average yields in their host regions, as reported in Table 6. These model farms must be adapted to climate zones, i.e., they have to be made zone specific. For terminal crops such as grain and potatoes, the available acreage at each model farm is multiplied by the regional and zone specific yield. Furthermore, output dependent costs are scaled according to the new output level.[14]

In production of milk and meat based on forage grass (in combination with feed concentrates), the model operates with a stipulated requirement of forage grass per head of different animals. The necessary level of acreage is then deduced from the yield in the specific region and zone, and acreage dependent costs are adjusted accordingly.[15] Fertilizer is assumed to vary with production and not with acreage (NILF 1990).

Finally, since pests and weed are positively related to temperature, the use of pesticides is assumed to increase. NILF (1990) estimated a doubling of the level of pesticides in grain and potato production, but no substantial extra need for clover and pasture. Therefore, compared with the average model farm level, grain and potato farms placed in zones 3, 4 and 5, carry extra costs for pesticides in the order of 50%, 100% and 150%, respectively.

Scenarios and results

The model is calibrated to reproduce the situation in 1998 as closely as possible. The resulting base solution is presented in column 1 of Table 7. Note that most agricultural employment takes place in rural areas, where labor-intensive milk and meat production dominates. Grain is mainly produced in central areas (the lowland of the south-east). Imports are low, with the exception of grain. The cold climate does not permit the growth of sufficient quantities of high quality grain for bread making. For the other main products, Norway is self sufficient, or has a surplus that is especially high for dairy products.

The policy scenarios are similar to those considered earlier. In the production efficiency case, it is assumed that the domestic production of each product must not fall short of the baseline level. An exception is milk, where self sufficiency is the floor (export is eliminated). The model will maximize economic surplus from agriculture subject to these floors, i.e., free competition is assumed. The necessary budget support in the form of deficiency payments follows endogenously from the shadow prices of the restrictions.

In the multifunctionality case, on the other hand, agricultural employment and land use are emphasized, and production is of secondary importance. Use of these inputs is assumed to be positively correlated to the provision of public goods such as landscape preservation and rural employment. As an illustration, land use and rural employment are made to equal 75% of the baseline levels. Since less emphasis is put on production, it would be reasonable to cut the import tariffs. Therefore, in alternative a) import tariffs are reduced to 25% of the baseline levels. However, to illustrate how the gains of a climate change depend on the import barriers, an alternative b) is considered, with prohibitive tariffs like today.

Table 7. Model results

	Base solution (1998)		Production efficiency				Multifunctionality							
							a) low import tariffs				b) prohibitive import tariffs			
			Status quo		Climate change		Status quo		Climate change		Status quo		Climate change	
Production and net imports (in parenthesis) (million kilos or litres)														
Cow milk	1671.5		1406.0		1406.0		963.9		958.0		1280.6		1321.1	
Drinking milk	635.4		691.5		691.5		698.8		697.1		675.2		683.1	
Cheese	87.7	(-28.5)	68.7		68.7		30.4	(39.0)	29.8	(39.3)	65.2		66.9	
Milk powder	14.5		6.2	(2.8)	6.2	(2.8)	-	(19.0)	-	(19.0)	-	(8.7)	1.3	(7.5)
Butter	22.3	(-10.2)	12.7		12.7		4.2	(10.4)	4.2	(10.4)	8.6		9.6	
Goat milk	22.2		22.2		22.2		20.8		-		17.4		16.9	
Beef and veal	92.6		92.6		92.6		38.9	(59.1)	38.7	(58.2)	73.9		85.5	
Pig meat	90.9	(0.9)	93.0	(0.9)	93.0	(0.9)	3.9	(109.0)	111.8	(0.9)	111.4	(0.9)	111.0	(0.9)
Sheep meat	23.0		23.0		23.0		26.5		29.8		8.4		17.0	
Poultry meat	27.0	(0.1)	27.3	(0.1)	27.3	(0.1)	27.7	(0.1)	27.8	(0.1)	29.2	(0.1)	28.4	(0.1)
Eggs	43.4	(0.7)	43.4	(0.7)	43.4	(0.7)	8.9	(36.7)	40.2	(5.5)	43.3	(0.7)	44.2	(0.7)
Coarse grains	1031.3	(135.0)	1031.3	(67.9)	1031.3	(67.8)	485.2		832.0		912.0	(135.0)	1101.4	
Wheat for human consumption	185.7	(278.0)	185.7	(278.0)	185.7	(278.0)	131.5	(350.3)	278.8	(203.0)	169.9	(278.0)	334.6	(138.9)
Potatoes	295.0		295.0		320.5		316.9		338.2		302.3		331.5	
Employment: (1000 man-years)	57.0		33.4		31.7		29.7		30.3		31.1		31.3	
Rural areas	38.2		18.8		16.8		28.6		28.6		28.6		28.6	
Central areas	18.8		14.6		14.9		1.1		1.7		2.5		2.7	
Land use: (million hectares)	0.83		0.69		0.47		0.62		0.62		0.62		0.62	
Rural areas	0.50		0.31		0.20		0.53		0.49		0.44		0.43	
Central areas	0.33		0.38		0.27		0.09		0.13		0.18		0.19	
Tilled fields	0.32		0.30		0.22		0.17		0.23		0.27		0.27	
Pastures	0.51		0.39		0.25		0.45		0.39		0.35		0.35	
Economic surplus: (billion NOK)	15.6		19.0		20.4		22.7		21.8		19.8		20.1	
+ Consumer's surplus	22.0		24.3		24.4		27.1		27.3		22.3		24.1	
+ Producer's surplus	1.6		1.2		0.3		0.3		0.2		0.7		0.2	
+ Tariff revenues	0.3		0.3		0.3		1.9		1.1		0.5		0.3	
- Taxpayers' expenses	8.3		6.8		4.6		6.6		6.8		3.7		4.5	
Support: (billion NOK)	15.0		11.6		9.4		7.7		8.6		9.7		9.6	
Budget support	8.3		6.8		4.6		6.6		6.8		3.7		4.5	
Border measures	6.7		4.8		4.8		1.1		1.8		6.0		5.1	

The “status quo” columns in Table 7 are benchmarks representing the present climate. Note that, irrespective of a climate change, substantial gains can be achieved for each alternative. If production efficiency were the sole policy target, economic surplus would rise by 3.4 billion NOK compared with the base solution, and budget support would decline by 1.5 billion NOK. There are three major explanations for these gains. I) The dumping of dairy products in foreign markets comes to an end, II) production takes place on bigger farms, and III) there is a relocation of production to the best agricultural areas. Naturally, this has negative effects on agricultural employment and land use, especially in rural areas.

In the multifunctionality case, the gains are highest with low import tariffs (7.1 billion NOK) because of cheaper imported food, and thereby lower domestic production. To meet the floors on land use and rural agricultural employment at the lowest cost, labor and land intensive farms in rural areas are favored (represented by small milk and sheep farms), and land intensive farms are preferred in central areas (represented by grain farms). When the present high tariffs are applied, elevated food prices finance more of the farmers’ support, at the expense of efficiency however. Nevertheless, in this case also, economic welfare exceeds the baseline level, by 4.2 billion NOK.

Consideration is now given to how a climate change affects these results. As discussed earlier, a one-level jump in climate zone is assumed for all regions. With regard to water availability, no effect on yields is assumed because the change in water supply is ambiguous and probably not a critical factor in Norway. Finally, owing to the CO_2 effect, yields in all climate zones are elevated by 18% for grain, 42% for potatoes and 36% for forage grasses.

Undoubtedly, a warmer climate has positive welfare effects in the production efficiency case. The same output levels can be provided with less inputs, especially land (–32%) but also labor (–5%) and other factors. Therefore, less budget support (–2.2 billion

NOK) is required to reach the production targets,[16] and economic surplus increases by 1.4 billion NOK.[17]

Only minor changes occur in the regional distribution of production. Since the productivity of the scarce tilled land in the south-east increases, even more grain can be produced in this productive region. On the relative fertile acreage elsewhere in central areas (i.e., in the south-west and the midlands) as well as in rural areas, milk and meat are produced. A comparison of columns two and three of Table 7, indicates that the rural versus central shares of employment and land use remain relatively unchanged.

When considering multifunctionality, the welfare effects of a warmer climate are ambiguous. Note that the plus or minus sign of the computed welfare effect depends on the import barriers. With prohibitive import tariffs, a 0.3 billion NOK gain is realized, whereas a 0.9 billion loss appears in the low tariff case. The only robust conclusion seems to be that gains of the same order as those realized in the production efficiency case are out of reach. Factors that have achieved higher productivity, i.e., acreage and labor, are not "allowed" to withdraw from agriculture, and support to maintain these factors also affects the input of capital and other goods, as well as production.

The ambiguity of the results needs an explanation, which is provided in Figure 3. S_0 and S_1 are supply curves (inclusive of subsidies) representing the present and future climate, respectively, and D is the demand curve. S_1 is more elastic than S_0 because productivity increases somewhat more in climatically unfavorable areas. An import price P_I and a tariff t, induce a domestic price P_D and consumption C. Production levels that correspond to the floors on land use and rural employment are X_0 and X_1 at the present and future climate, respectively. The difference between consumption and production is imported.

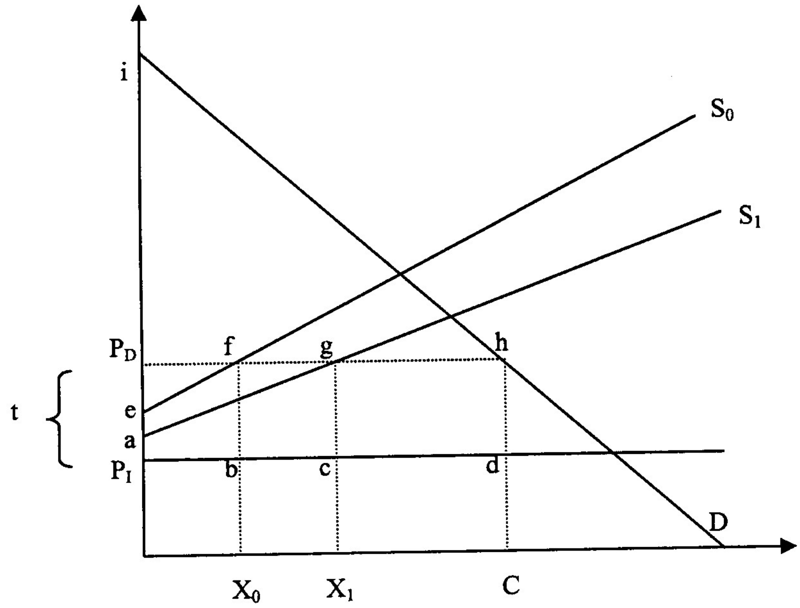

Figure 3. Welfare effects of a warmer climate

In the present climate, economic surplus is the sum of the consumer's surplus (triangle $P_D$hi), producer's surplus (triangle efP_D) and tariff revenues (rectangle bdhf), with deducted subsidies (not shown in the figure). Increased productivity due to climate change elevates production to X_1. This affects the producers positively (area agfe), but lowers tariff revenues (area bcgf). If the decline in tariff revenues exceeds the producers' gain, welfare becomes lower.[18] This is most likely to happen if the import price P_I is low compared with the tariff t. The economic rationale behind this result is that expensive domestic production substitutes for cheaper imports. If tariffs are prohibitive, like today, the market solution appears at the intersection of the demand and supply curves. Thus, a warmer climate is welfare improving because higher production also benefits domestic consumers.[19]

In the low tariff case, it can be seen that a warmer climate particularly favors the production of grain and potatoes in combination with pig meat and eggs. Several explanations are plausible. Grain production is land intensive, and therefore profits from the acreage subsidies. Additionally, a better climate directly affects grain and potato productivity, as opposed to meat production where only part of the costs are affected (animal care expenses, for example, are not changed). When import costs are low, rural agricultural employment is *less costly* for pig and egg farm operations. However, if importing is not an option and prices are higher, milk and sheep farms become more profitable.

Conclusions

For a cold climate country such as Norway the predicted climate change will certainly increase agricultural productivity. Target output levels can be achieved with less inputs, particularly of land, but also of labor, capital and materials. This may reduce the high financial burden of the agricultural policy. In the case of the current level of self-sufficiency, the model simulations suggest that budget support savings of about 2 billion NOK can be achieved, i.e., about 15% of the present level of support expenditure.

However, self sufficiency, which may be regarded as high production levels, is neither a rational nor a possible target for future Norwegian agricultural policy. Irrespective of any climate change, agriculture will generally not be competitive in these regions. Arguments that are more valid are those supporting environmental and public goods in the form of landscape and biodiversity preservation, and rural settlement. In any case, Norway may be obliged to adopt such policies because of future WTO agreements.

The multifunctionality scenario is therefore the most realistic for Norway and northern agriculture. When high levels of land use and rural employment are emphasized instead of production, the projected efficiency gains cannot be achieved. Factors that have attained higher productivity, i.e., acreage and labor, are not "allowed" to withdraw from agriculture.

Support to preserve these factors also affects the input of capital and other goods as well as production, since inputs variously depend upon each other.

This paper demonstrates that the welfare gains of a warmer climate are ambiguous when multifunctionality is considered. The sign and magnitude of the welfare effect depend both on the type import barriers and, in particular, on how easily the factors of production can substitute for each other. When domestic production displaces far cheaper imports, a warmer climate may in fact result in less economic welfare.

Nevertheless, a warmer climate will most likely be welfare improving in the multifunctionality case as well, even though the effect may turn out to be weak. The reason is that extensive production techniques can be employed, i.e., techniques using little input of capital and other goods per unit of land (e.g., grazing). Furthermore, to reach the employment floor with minimal side effects on other costs, labor intensive techniques beyond those represented in the model, can be employed.

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Footnotes

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[1] Northern regions include areas such as Alaska, Iceland, Norway, and northern parts of Canada, Russia, Finland and Sweden.

[2] Normal yields for wheat and potatoes in Norway are 4320 and 23,900 kg per hectare, respectively. The weighted average yields in 2000 for Denmark, Belgium, Luxembourg, France, Netherlands, United Kingdom and Germany were 7340 and 41,040 kg per hectare, respectively (Statistics Norway, 2000).

[3] For the USA, for example, there is a large body of studies that, according to an assessment by Lewandrowski and Schimmelpfenning (1999), suggest relatively small economic impacts for the US economy and agriculture, especially when taking farm level adaptations and geographical relocation of production into account. The effects on world food supply are also predicted to be moderate as reduced production in some areas is balanced by gains in others (Rosenzweig and Hillel, 1995). As pointed out by Reilly and Hohmann (1993), interregional adjustment of production and consumption because of price changes and international trade, will buffer the severity of climate change impacts on world agriculture. However, it is acknowledged that some regions will benefit and others will lose. Most studies predict that developing countries will be generally negatively affected, and high-latitude regions will be the beneficiaries (see, for example, Reilly (1995), Mendelsohn and Dinar (1999) and Leemans and Soloman (1993)).

[4] This is only 3% of the total surface of Norway. A large part of the surface is taken up by mountains and sub-arctic regions, and forests cover about one third of the country.

[5] GS is the number of days from when the plants start to grow to when they finish growing. Skaugen and Tveito (2002), whose figures are reported, use 5°C as a threshold.

[6] GDD is defined as the accumulated sum of °C between the daily mean temperature and the threshold temperature.

[7] More insect and disease damage is a potential negative factor of longer GS.

[8] Using a biophysical statistical model, Torvanger et al. (2003) analyzed the relationship in Norway between yields of potatoes, barley, oats and wheat, and temperature and precipitation for the period 1958–2001 at the county level. On the basis of the RegClim scenario, they predicted potato yields to increase by 25–30% in

some parts of the country. They found grain yields to be less responsive to changes in temperature. Clover and pastures were not included in their analysis.

[9] According to Parry (1990), evaporation increases by about 5% for each degree Celsius of mean annual temperature (at mid-latitudes).

[10] A doubling of the ambient CO_2 concentration may reduce transpiration by more than 20%; see Parry (1990).

[11] The Free-Air CO_2 Enrichment (FACE) approach seems to be the most realistic technique to create higher-than-normal concentrations of atmospheric CO_2 to study the impacts of CO_2 enriched air on plant growth and development (Idso et al. 2002).

[12] Substitution parameters that correspond to the Hicks–Allen substitution elasticities are given by the expression below (see Sato 1967), where σ is the top level substitution parameter, θ_s is the cost share of nest s, σ_s is the substitution parameter of nest s and σ_{ij}^{HAS} is the Hicks–Allen substitution elasticity between the goods i and j. N_s is nest number s (s = 1,…,S). In the low (high) flexibility case, the parameters are as follows: $\sigma_y = 0.1$ (1), $\sigma_q = 0$ (0) and $\sigma_z = 0.717$ (1.686).

$$\sigma_{ij}^{HAS} = \begin{cases} \sigma + (\sigma_s - \sigma) & i, j \in N_s, i \neq j \\ \sigma & i \in N_r, j \in N_s, r \neq s \end{cases}.$$

[13] Relative differences in yields between zones are assumed to be invariant of region.

[14] Costs attributable to the extra production of grain and potatoes on the same acreage are low, and are related to extra handling and storage costs. It is assumed that 2% of labor costs and costs related to buildings and machinery are attributable to the production level and not to the acreage *per se*. Thus, these costs are scaled by $(1 + 0.02\Delta X/X_0)$, where ΔX is the change in production and X_0 is the initial level of production. For grain and potatoes in combination with pigs, eggs or chicken, 1% is applied.

[15] Labor effort per hectare of acreage (meadow) is estimated to 34.7 hours a year (Gaasland et al. 2001b). The following cost components of the model are fully attributed to acreage: plants, seed and pesticides, capital

costs related to ditches, as well as maintenance and operation of ditches, water and soil. 95% of the maintenance and operational costs of machinery and tools are attributed to acreage, but only 5% of their capital costs. In other words, it is assumed that the operational costs of the machinery correlate to a large extent with the size of the acreage, but not the capital costs.

[16] Compared with total budget support in the base year 1998, amounting to 12.1 billion NOK, this constitutes 18%.

[17] Since the consumer's surplus is mainly unaltered, the increase in welfare equals the decline in production costs (1.4 million NOK). With regard to budget support, 2.2 billion NOK can be saved, albeit at the expense of the producers. The producer's surplus decreases because the rise in productivity is highest in climatically unfavorable areas. In other words, the aggregate supply becomes less sensitive to price (flatter supply curve), and the rents thereby decrease.

[18] As is the case in the low tariff alternative. Note that tariff revenues decline by 0.8 billion NOK, whereas producer's surplus and budget support are mainly unaltered.

[19] The computation with prohibitive import tariffs shows that the consumer's surplus rises by 1.8 billion NOK. Lower prices necessitate more budget support in order to reach the targets on land use and rural employment (0.8 billion NOK). The producer's surplus decreases (0.5 billion NOK), mainly because the supply curve (inclusive of subsidies) turns flatter when acreage and wage subsidy rates increase. This is due to the fact that the subsidies in general represent a lower share of the costs for production efficient farms (lower part of the supply curve) than for high cost farms. In sum, economic surplus increases by 0.3 billion NOK.