Turning climate change information into economic and health impacts

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Abstract

The PRUDENCE project has generated a set of spatially and temporally high-resolution climate data, which provides new opportunities for assessing the impacts of climate variability and change on economic and human systems in Europe. In this context, we initiated the development of new approaches for linking climate change information and economic studies.

We have considered a number of case studies that illustrate how linkages can be established between geographically detailed climate data and economic information. The case studies included wheat production in agriculture, where regional climate data has been linked to farm enterprise data in an integrated model of physical conditions, production inputs and outputs, and farm management practices. Similarly, temperature data were used to assess consequences of extreme heat and excess mortality in urban areas.

We give an introduction of an analytical approach for assessing economic impacts of climate change and discuss how economic concepts and valuation paradigms can be applied to climate change impact evaluation. A number of methodological difficulties encountered in economic assessments of climate change impacts are described and a number of issues related to social and private aspects of costs are highlighted. It is argued that, in particular, detailed climate information matters in relation to understanding how private agents react to observed climate data.

Introduction

There are several analytical problems related to the use of climate data in economic assessments due to inherent structural mismatches between the spatial and temporal organisation of climate- and economic data. Climate models operate in a geographical context, whereas economic analysis is structured around economic decisions or institutional boundaries for decisions within enterprises (e.g. farms), agricultural markets, urban environments, or political bodies like the European Union. A special effort is therefore needed to transform climate change data into an information structure relevant for economic decisions.

In addition to these spatial issues in data organisation, there are also temporal scale differences between climate modelling and economic analysis. The climate modelling exercise which was conducted in the PRUDENCE project focused on the time period 2071 to 2100, which is considered to be a relevant time frame for climate models to establish significant results. However, this time frame is very difficult to relate to economic studies, where decisions typically have a much shorter time horizon. Most economic decisions (e.g. farm production practices) have a time horizon of less than 10 years, other decisions like investments in power systems, industry, and infrastructure can have a longer lifetime of 30 to 50 years, but very few decisions span as long a period as the PRUDENCE focal period of 2071 to 2100.

The time frame mismatch between climate modelling and economic studies[1] creates several serious methodological problems in relation to climate change impact and adaptation studies. Economic studies will traditionally compare a baseline case with no climate change with a case that assumes climate change to happen, and in such an analysis it necessary to have a fairly detailed picture of non-climatic trends of relevance to the impacts concerned, e.g. land use structure, agricultural practices, and human settlements. For structural reasons, economic studies of climate change impacts will most often have to show the transition over the whole period from the present to 2100, so it is not enough to use specific climate data for the 2071 to 2100 period.

Given these methodological limitations, we have pragmatically considered how projected future changes in climate variables generated by the PRUDENCE team could influence economic systems if these systems were characterised by technologies, production practices, and market conditions like today. Expected development trends in the economic systems, then have been addressed in sensitivity analyses, where the implications of technological development trends and other assumptions have been considered. It is recognised, that such a representation of economic systems does not fully reflect future conditions for 2071 to 2100. However, the approach has the advantage that the economic systems can be represented in a very detailed way drawing on present day conditions, which would not have been possible if the analysis was based on long-term economic scenarios that would be very aggregate. In this way the climate data work as an exogenous internally consistent set of variables, despite the fact that they do not completely match the time perspective of the economic analysis. The implications of this methodological limitation will be discussed in relation to the case studies provided in this paper.

Economic Concepts Applied to Climate Change Impact Evaluation

Climate change implies a broad array of impacts on natural assets that have value in the production of market goods as well on other goods like environmental services, biodiversity, and aesthetic values. The aim of economic studies is to assess the potential loss of these values and how these eventually can be mitigated by climate change adaptation policies. An approach for assessing economic impacts of climate change is suggested by Antle (1996).

[1] It is particularly difficult to link geographically detailed long-term climate data with economic studies since economic models have a tendency to be very aggregate when applied to long time horizons.

According to Antle, climate change, together with other environmental impacts, has a number of economic, environmental and human health impacts within a human population and a geographical area. Following that, Antle suggests to estimate the welfare costs of climate change as the difference between the ex ante value of a number of indicators of the economic, environmental, and health status under the present climate, and the expected value of the same indicators assuming future climate change. The expected values are based on a summary statistic measure say, *welfare, W* $(e_t$[2]$)$. The costs of climate change, accordingly can be defined as:

$$W = W(e_1) – W(e_0) \qquad (1)$$

Where the net cost, or benefit, W, is represented by the difference between welfare under different assumed states of economic, environment and health aspects (e_0 and e_1).

It must be expected, that people will respond to climate change impacts for example through technology use, changed land use patterns, and changes in agricultural management. The welfare implications of climate change, therefore should be adjusted to reflect the costs and benefits of human adaptation efforts in order to establish an estimate of the net costs of climate change. Following that, the net welfare costs of climate change should include an adjustment factor $a\ (e)$ and will then write:

$$W = W(e_1, a\ (e_1)) - W(e_0) \qquad (2)$$

The factor *e* represents the state of the economic, environmental and health aspects before and after climate change impacts, given no human adjustment takes place, and $a\ (e))$ represents adjustments to the changed climate.

It is easiest to take the adjustment factor into consideration in short-term analyses, where responses to climate change can be assessed in relation to knowledge about the climatic sensitivity of existing systems.

The actual adjustment to a changing climate can either be a response to already observed changes in climatic conditions or can be based on expectations about future change. This difference in perspective is referred to in the literature as autonomous versus anticipatory adaptation. IPCC (2001a, page 883) defines autonomous adaptation as actions that take place – invariably in reactive response (after initial impacts are manifest) to climate stimuli – as a matter of course, without the direct intervention of a public agency. Anticipatory adaptation is a result of a deliberate policy decision on the part of an agency based on the awareness that conditions are about to change or have changed and that action is required to minimize losses or to benefit from opportunities. Autonomous adaptation is widely interpreted as initiatives by private actors rather than by governments, usually triggered by market or welfare changes induced by actual or

[2] The summary statistic measure can either be aggregated over all elements in the welfare function or can be represented as indexes of different indicators. In the case where the welfare is represented as on aggregated outcome the approach can be addressed as a traditional welfare optimization problem.

anticipated climate change. In contrast, anticipatory adaptation is associated with public interventions (IPCC, 2001a, p. 884).

Another way of looking at how experienced information on climate change can be used in creating expectations about the future is to consider, if annual climate variations are thought to be part of an "existing" and stable distribution of climate variables or if experienced climatic variation can be associated with a more permanent climate change and thereby a "new" distribution. These alternative approaches are illustrated in Figure 1.

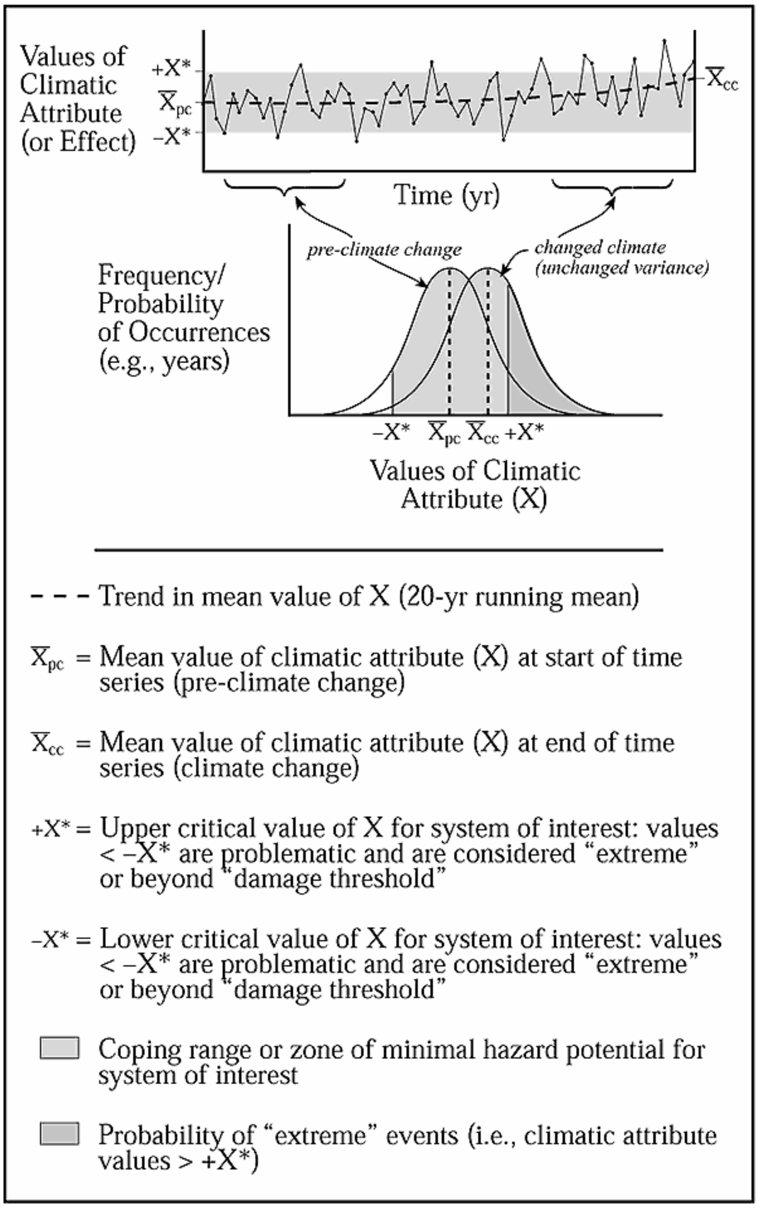


Figure 1 Stylised Representation of Observed Values of Climate Parameters and Expected Future Values (IPCC, 2001a, p. 883).

The development over time in mean and short-term variability of a climate attribute is illustrated in Figure 1. The shaded area illustrates the coping capacity of a system as a variation in the climate attribute. This concept can be illustrated for the effects of short-term climate variations on farm level decisions about crop choice. The first step will be to transform the climate attribute *X* into a production attribute *C*, and to derive a climate dependent distribution of the *C* variable.

The farmer can choose to base his production strategy on the expected climate mean value X_{xc}, and the corresponding expected crop yield, C_{xc}. The farmer's expectations can be formed in different ways and can either be based on his own weather experiences, on more formalised weather statistics, or on expected climate change. The actual creation of expectations by farmers depends on publicly available information, and on how farmer understand observed weather in relation to underlying frequency distributions of climate change and the impacts on crops.

Measured in terms of profitability, the farmer in this framework should base his economic decisions on the expected value of:

$P = P\ (C_{xc},\ p_{xc})$, where

P is the profit, C_{xc} is the crop production given assumptions about climate change, and p_{xc} is the crop price that depends on agricultural subsidies and global production levels. It is here worth recognising that the global production of specific crops does not need to be influenced symmetrically by climate change, so relative high and low production in different regions of the world can offset each other.

In the case where the climate is similar to the historical state corresponding to $X_{pc,}$ the farmer should not invest in more land, buildings or other production facilities than what otherwise would have been profitable. Conversely, in the case where climate change is expected to support increased crop production corresponding to $X_{cc,}$ the farmer might consider expanding his investments.

Figure 1 also includes an indication of coping range and probability of extreme events, which in the case of agricultural production can be understood as relating to critical minimum climate conditions for growth and extreme values that seriously will damage growth. Extreme climate parameter values like +X* and –X* in Figure 1 are defined to reflect threshold values of damages which depend on the system that is affected.

The distribution of climate attributes needs to be transformed into a distribution of climate dependent consequences like excess mortality in order to determine threshold values for extreme economic losses or extreme health impacts. It is important to keep in mind that extreme values of climate parameters do not need to be directly related to the corresponding distribution of extreme economic losses or health impacts.

Some agricultural crops at specific locations might be sensitive to small temperature or precipitation variations around the climatic mean implying that an extreme loss of the crop is relatively likely, other crops are very insensitive to climatic variability at specific locations, so losses are very unlikely. In the same way excess mortality due to heat waves are not directly linked to absolute temperature levels, but is in a more complex way related to the interactions between temperature development over time, humidity, urban settlement structures, lifestyle, and health care systems. The following includes a more detailed discussion about how climate data and economic information can be linked in relation to the agricultural sector and health.

A case study for wheat cultivation in Denmark demonstrates how future climate change as predicted by detailed regional models in PRUDENCE will influence farm outputs in Denmark. The assessment is based on an econometric model of farm management practices and performance under different climate conditions. It is shown that predicted future climatic changes will have a significant impact on the mean values and the distribution of wheat yields in Denmark, but the actual magnitude of the impacts strongly depend on future technological improvements in the sector, which are considered in a sensitivity analysis.

The use of detailed climate model date in relation to health studies are illustrated in relation to a study of the excess mortality that was caused by the heat wave in Europe in the summer of 2003. An approach for assessing the costs and benefits of adaptation options are presented based on the results of various health impact studies for the United States and Europe.

Detailed Assessment of Climate Change Impacts on Wheat Production

Agriculture has a number of unique production features. Agricultural production is a sequential process, where the inputs and timing of input responses at several stages of production are crucial for the harvest-outcome. The unpredictability and stochastic nature of weather that influence at all stages of crop production are key to understanding the production condition in agriculture. Agriculture is therefore one of the economic sectors most directly affected by climate change.

The impact of climate change on wheat production in Denmark was studied with an econometric model that links farm enterprise surveys with concurrent meteorological data and the HIRHAM/HadAM3H A2 scenario for 2071-2100. The model has been used to estimate the relationship between wheat yields and production inputs, soil conditions, management practices, temperature and precipitation. Previous studies have shown that temperature and precipitation are the most important factors determining wheat production in Denmark (Olesen et al., 2000a). It is concluded that regional and time specific climate variations are major factors behind production outputs. Linking detailed farm enterprise surveys and climate data in this way provides key information about vulnerabilities and adaptation strategies.

Climate parameters have a very complex impact on crop production, where radiation, precipitation, and temperature as well as temporal variation in the climatic factors matter (Olesen and Bindi, 2002). The temporal variation of climate variables matters as plant growth is a multi-stage process with different climate requirements. While earlier stages of cereal growth need sufficient temperature and soil water, final ripening and yields depend on sufficient radiation. However, too much precipitation can make soils unworkable in crucial periods, such as during sowing and harvest (Rounsevell and

Jones, 1993). It is therefore important to take detailed time specific distributions of climate parameters into consideration rather than relying on average annual mean values. Detailed regional analysis for Denmark confirms these complex relationships between climate parameter variations and wheat yield (Kühl, 2005).

The present study focuses on the effect of climate change on the yield of winter wheat. Winter wheat is the highest yielding cereal and thus the most attractive crop in the Danish climatic context. The duration from sowing to maturity for winter wheat depends on temperature and in many cases also on day length. It is to be expected that increased temperatures will shorten the period in which the crop can accumulate biomass, and the yield is thereby reduced (Olesen et al., 2000a). The yield, however, will also be influenced by a number of other indirect impacts from climate change that have to be taken into consideration in the crop management. On the one hand, biomass growth will benefit from increasing atmospheric CO_2 concentrations (Tubiello and Ewert, 2002), on the other hand, higher temperatures may cause increased insect pests and diseases implying increased production costs and lower outputs (Olesen and Bindi, 2002).

The actual net impacts on wheat outputs of these different indirect climate related factors have been studied in controlled environments, but it has not yet been possible to establish realistic test conditions that can integrate all the above mentioned indirect factors (Olesen et al., 2000a). The literature has in particular reported results on the yield impact of increased atmospheric CO_2 concentration (Kimball et al., 2002) showing average yield increases of 28% for a doubling of CO_2 concentration, with larger relative increases under dry conditions due to higher water use efficiencies arising from increased CO_2 concentrations.

Model Specification and Results

In the present study wheat yields were modeled with a descriptive econometric model based on farm level information and observed weather. This approach takes the farm-level decisions and management as given, integrating the additional variation and downward bias in the yield outcome relative to controlled experiments. The crop yield *y* is modeled as

$$y = f\left[f_1\left(x^1, y_0, e^1\right), \ldots, f_m\left(x^m, y_{m-1}, e^m\right)\right] \qquad (3)$$

where the harvested yield is the outcome of a multi-stage process. The growth in each stage *m* is conditional on the state of the crop in the previous stage *m-1*, the input factors x^m and stochastic impacts e^m, mainly representing weather outcomes in the specific production stage. We used bimonthly data of local precipitation and temperature to reflect the differential impacts of weather at different stages.

Equation (3) was calibrated for the period 1992 to 2003, based on farm enterprise data from a representative statistical sample of agricultural enterprises in Denmark coupled with interpolated weather station data on temperature and precipitation for a 10*10 km grid. The agricultural data included crop yields, production inputs, management practices and soil quality.

The parameter estimates are shown in Table 1. The meteorological data shows as expected a strong impact on wheat yields, as do the soil type and organic farming practices. Moreover, even over this comparably short period of time an upward trend in wheat yields is observable.

Figure 2 combines the actual, observed distribution of yields with the estimated distribution and the simulated future wheat production for 2071 to 2100, based on climate change projections from the HIRHAM/HadAM3H A2 scenario.

Figure 2 confirms that the estimated results for 1992 to 2003 seem to fit the actual wheat production reasonably well despite that the estimated distribution is slightly more centered than the actual. Applying the projections for 2071-2100 results in a decrease in wheat yield, and the mean of the forecasted yield distribution is about 13% lower than the mean of the current wheat yields. This is in line with the findings of other climate change studies for Denmark that similarly projects that a higher temperature ceteris paribus leads to a shorter grain filling period and therefore a lower yield (e.g., Olesen et al., 2000a).

To compare the dispersion and the mean of the wheat yield distribution with and without climate change figure 2b presents a quantile-quantile plot of the present yields against the forecasted yields. The change in the mean yield value is reflected in the downwards displacement of the yield relative to the diagonal of Figure 2b, while a change in the dispersion of the two distributions can be seen by a slight clockwise tilt of the predicted yield distribution relative to the diagonal. This indicates a small reduction in the overall yield variance under climate change.

Figure 2: Forecast of Danish Wheat Yield with Climate Change from 2070 to 2100 and Observed Yield from 1992 to 2003

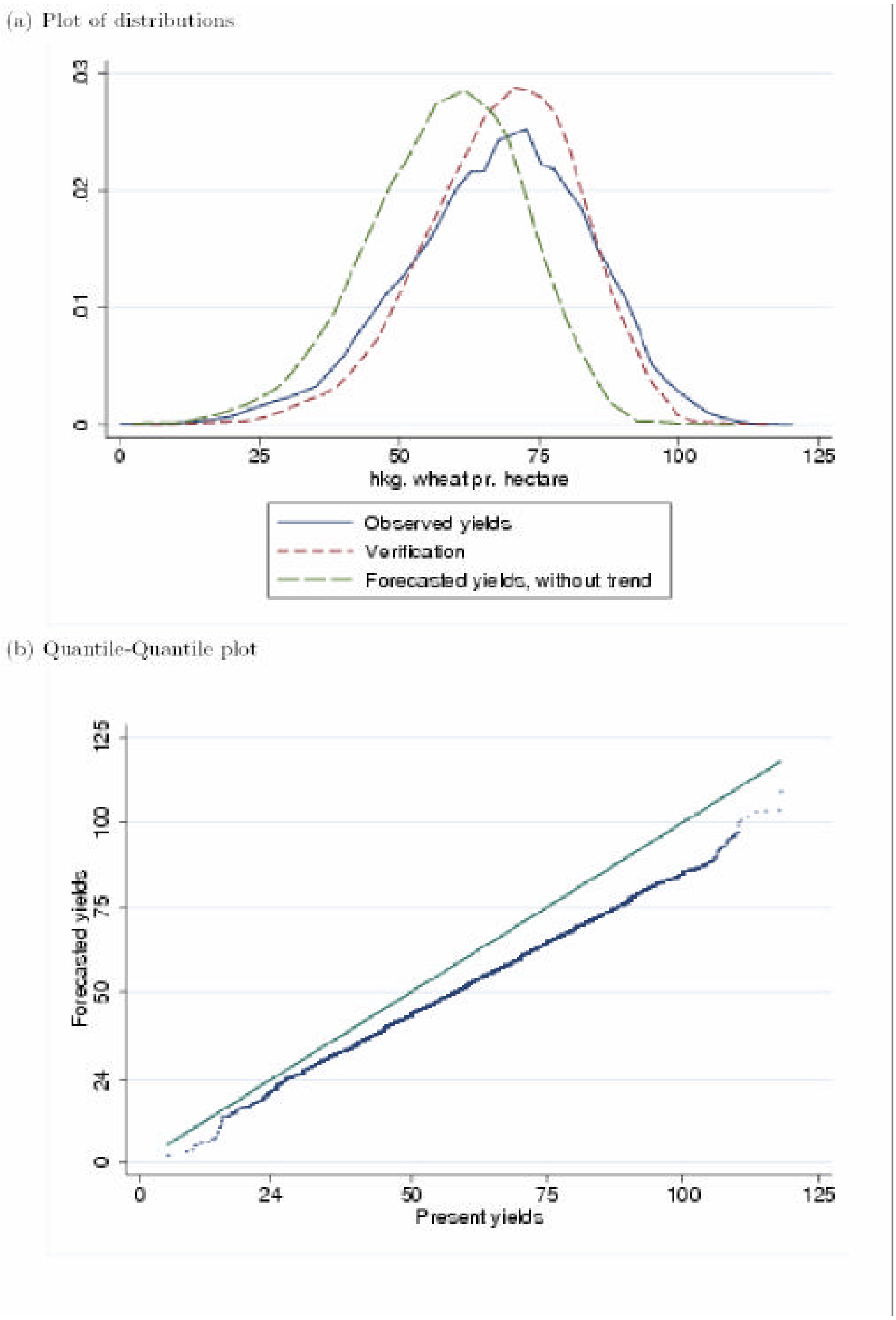


Table 1 Estimation Results

Wheat, hkg/ha	
Pct. ler på landbrug	-1.432***
	(0.493)
Organic	-15.545***
	(1.806)
Pesticides	0.014***
	(0.005)
Mineral fertilizer	-0.002
	(0.006)
Pct. grain, lagged	-1.462***
	(0.397)
Full-/Part-time	0.056
	(0.789)
Trend	7.255***
	(0.518)
Rain, autumn	-0.001
	(0.003)
Rain, winter	0.009***
	(0.002)
Rain, spring	-0.041***
	(0.004)
Rain, summer	-0.019***
	(0.002)
Temp., autumn	-1.287***
	(0.178)
Temp., winter	1.603***
	(0.143)
Temp., spring	-2.151***
	(0.209)
Temp., summer	-0.847***
	(0.108)
Constant	99.948***
	(2.841)
Observations	14877
Farms	5112
F(27,9738), overall	33.94***
F(12,9738), tobit-res.[a]	9.59***
F(8,9738), meteorol. var.	59.61***
R2 within	0.09
R2 between	0.13
R2 overall	0.09

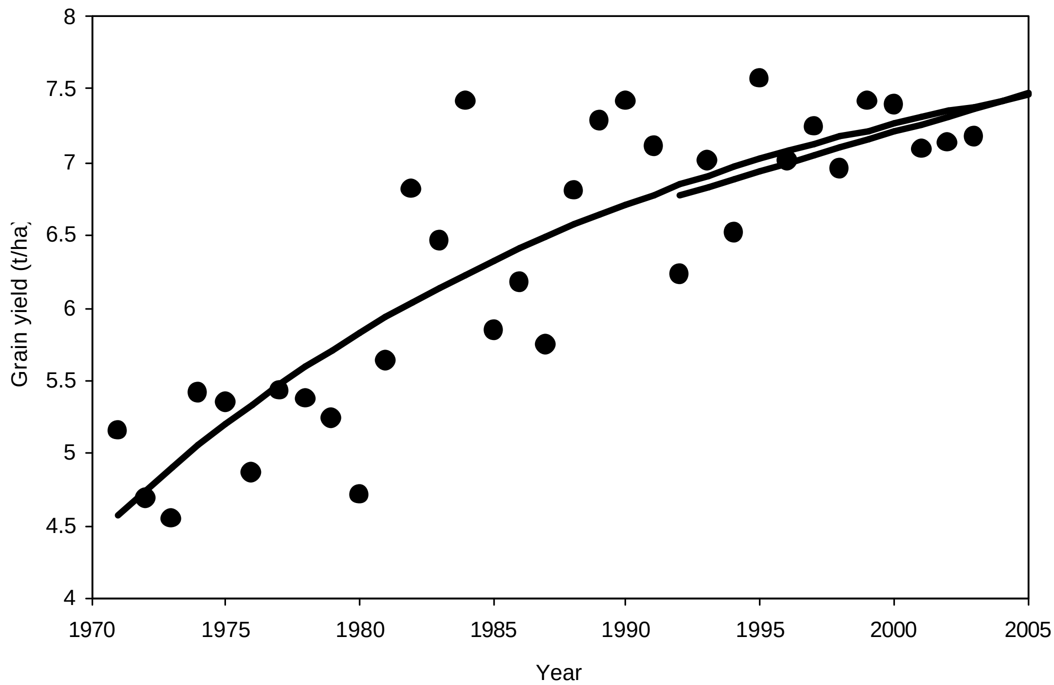
Sign. levels: *: 10% **: 5% ***: 1%
(Standard errors in parentheses)

As noted before, the presented yield projections do not fully integrate the impacts of increased CO_2 concentrations and other indirect climate change impacts, so that the magnitude of the production impacts is not fully assessed. The effect of increased CO_2 concentration has been assessed in the literature, and is expected to contribute to an increase in grain yield of 30% for a doubling of the CO_2 concentration (Olesen and Bindi, 2002). For the IPCC SRES A2 and B2 scenarios the expected yield increases in winter wheat for 2071 to 2100 due to increased CO_2 are forecasted to be 30% and 25%, respectively.

Climate Change Impacts under Different Technology Scenarios

Another limitation of the modeling results above is that they have not taken future improvements in production efficiency into account. It is important to recognize the large uncertainties that arrive due to the gap between the time frame of the farm enterprise data that has been used to estimate the model and the time frame of the climate projections. As the wheat yield model is estimated in the data-specific context of the 1992 to 2003 period, the parameters reflect the current technological restrictions on agricultural production, which do not need to represent all relevant aspects of production conditions over the scenario period, where new higher-yielding and possibly better adapted varieties as well as better cultivation techniques may be introduced. The importance of this factor is illustrated in Figure 3 that shows average wheat yields in Denmark during the period 1970 to 2003.

Figure 3 Development in National Average Grain Yield of Winter Wheat in Denmark 1970 to 2003 (Data is based on FAO Statistics)



The average winter wheat yield per ha has increased by as much as 60% from 1970 to 2003. The largest increases were obtained between 1970 and 1990 due to a combination of better varieties, better fungicides and increased fertiliser use (Olesen et al., 2000b).

Future technological improvements has been taken into consideration in the econometric model in a sensitivity analysis, where production efficiency improvements have been integrated in two alternative cases. Case 1 assumes a decreasing technological change relative to the estimation period (Figure 3), whereas Case 2 assumes technological improvements to continue with the same speed in the future as observed in the model validation period from 1992 to 2003. It is in both cases assumed that technological improvements in the climate change scenario will have the same magnitude as without climate change. Figure 4 shows the results of the Case 1 assumptions on technological improvements, and Figure 5 shows the results of the Case 2 assumptions.

It can be seen from Figures 4 and 5 that the mean yield decreases with climate change in line with the results shown in Figure 2a, but the yield decrease caused by climate change is offset by productivity increases. Case 1 results in an increase in the mean yield of about 10% in the climate change case compared with about 25% without climate change. Case 2 results in an about 72% increase in wheat yield with climate change and about 90% increase without climate change.

Future wheat yields in absolute terms are thus expected to increase in Denmark from the first time period, 1992-2003, to the second, 2071-2100, even though future temperature and precipitation patterns will offer less favorable production conditions than under the present climate. Technological improvements in both Case 1 and Case 2 are expected to be large enough to offset the negative yield impacts from climate change. However, wheat yields still will be lower with climate change than in the baseline case that assumes continuation of today’s climate. Similar results have been suggested for the effects of climate change for farmers in the corn belt of US (Kim and Chavas, 2003) and for European crop production affecting land use in Europe (Rounsevell et al., 2005).

The projections of improved productivity of winter wheat in Case 1 and 2 are smaller than indicated by the analysis of improved productivity of wheat in Europe performed by Ewert et al. (2005). This shows that the uncertainties regarding future technological improvements may be considerably higher than those related to climate change impacts.

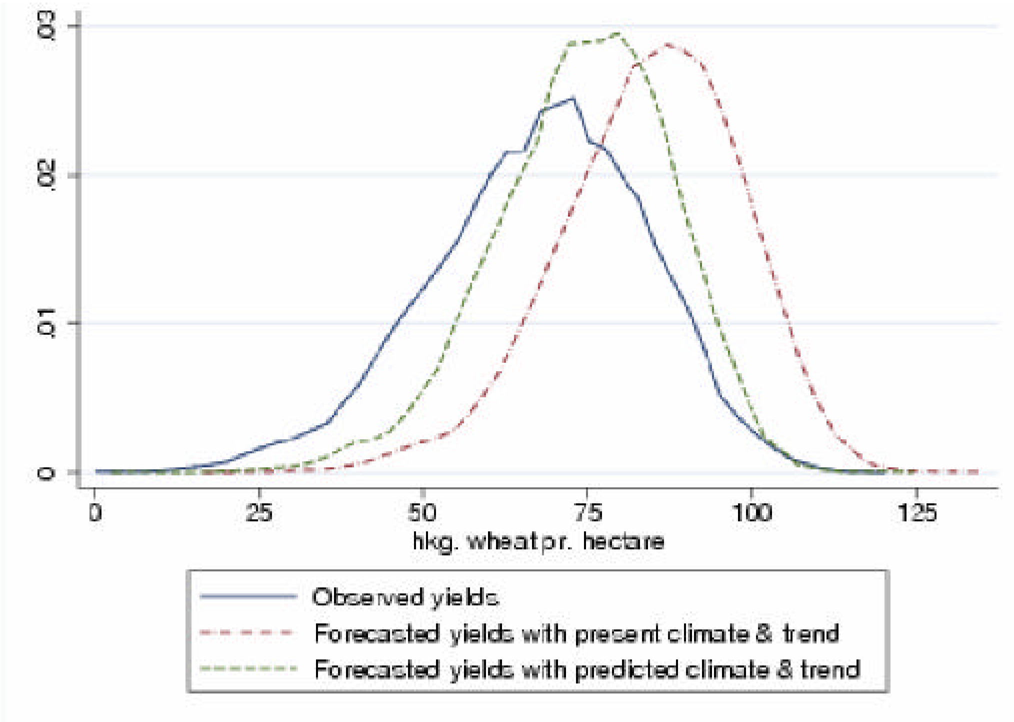


Figure 4. Forecasted Yield with Decreasing Rate of Technological Progress over Time (Case 1)

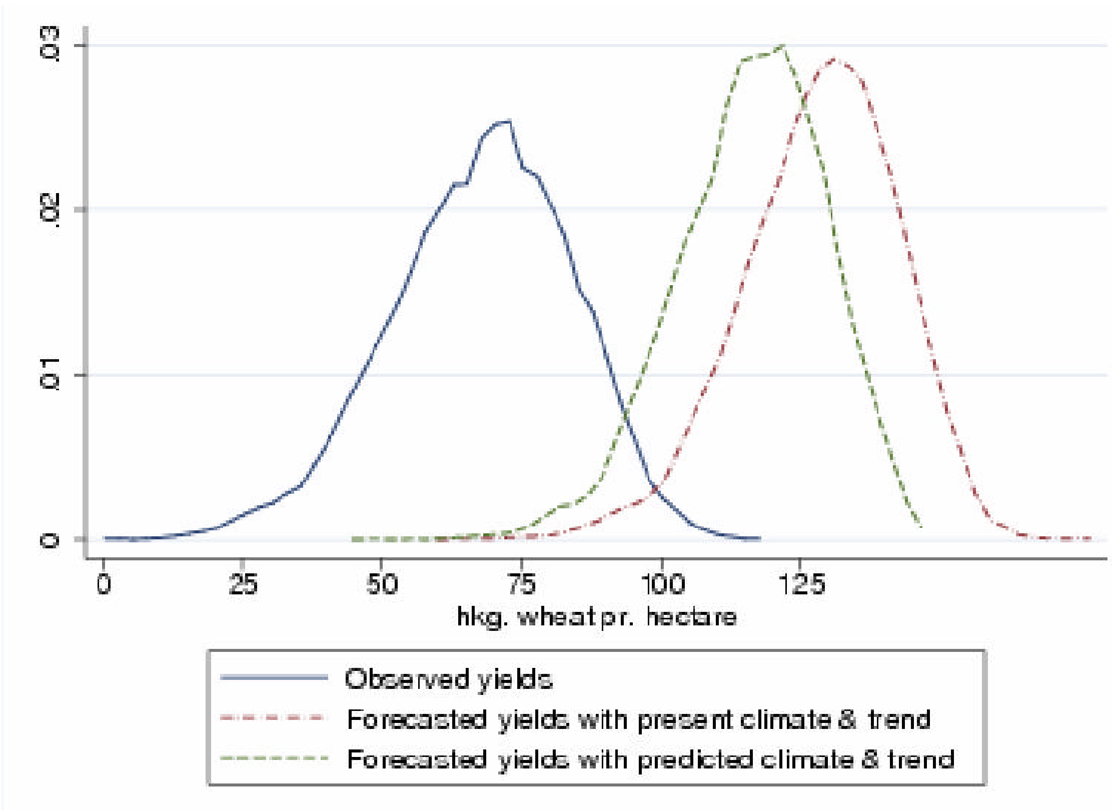


Figure 5. Forecasted Yield with Constant rate of Technological Progress over Time (Case 2)

Substitution and trade effects
The present analysis has focused on one crop and has shown that climate change has a negative impact on growing conditions for winter wheat in Denmark with current technology. With different scenarios on technological progress this decline is turned into a net increase in the mean wheat yield.

Other crops require different profiles of moisture and radiation over the growth cycle, and differential impacts of climate change on other typical crops in Danish agriculture can be expected. The grain yields of spring cereals are thus less impacted by climatic warming than winter cereals, because there is large scope for adapting the sowing time in spring cereals (Trnka et al., 2004; Olesen, 2005). The indirect effects of climate change on crops through changes in the growth pattern of weeds and the frequency and strength of pests will also affect crops differently. Climatic change will therefore – *ceteris paribus* – almost certainly change the relative returns of the typical crops of Danish farms, as well as make currently marginal crops profitable. A warmer climate will for instance shift the northern range of maize to cover a larger part of Denmark. The area of silage maize has increased substantially in Denmark over the past 10 years (Olesen and Bindi, 2004), and a climatic warming of further 1-2 °C should make it possible to grow grain maize in Denmark (Kenny et al., 1993).

A full picture of the relative changes in yields and returns for agricultural crops therefore requires analysis along similar lines for a range of crops. To uncover the general equilibrium effects on crops rotations and agricultural supply such studies can enter into farm-level multi-crop and -activities models, be it dynamic whole-farm models like FASSET (Berntsen et al., 2002) or econometric models like ESMERALDA (Jensen, 1996).

Climate change will affect distinct agro-ecological systems differently worldwide, and can under varying circumstances lead both to decreases and increases in the yields of specific crops, and to shifts in cultivated crops. Countries will therefore experience relative changes in the profitability of growing wheat (and other crops). This will gradually change the worldwide trade pattern with wheat. The above analysis has shown an increase in yields in Denmark with the projected 2071-2100 climate and technological progress. However, similar developments in climatic and in technological change will take place in other countries, and we cannot, based on present study, conclude whether it will be more or less profitable to grow wheat in Denmark, relative to other countries.

Health Impacts of Extreme Heat Waves in Europe

The summer of 2003 was characterised by an extreme heat wave in Europe, which according to the WHO directly resulted in the deaths of about 14,000 elderly people in Paris, and about 2000 in the United Kingdom and in Portugal (WHO, 2004). The PRUDENCE project has supplied new scenarios for the probability of extreme heating events in Europe under future climate change that suggest that such health impacts could be magnified under future climate change (Schär et al., 2004). The potential for using such climatological studies as an input to the assessment of health impacts due to extreme heat and the costs of adaptation measures are discussed in the following section.

The consequences of the 2003 heat wave has initiated a number of studies that in detail considers the costs and benefits of coping strategies that reduce over-mortality of extreme heat events in Europe. The World Health Organisation (WHO, 2004), examined the relationship between extreme heat, mortality among elderly people, and the costs and benefits of warning systems in Europe (Kovats et al, 2004). Similarly a number of studies from American cities have assessed over-mortality and benefits of extreme heat warning systems (Knappenberger et al., 2004; Weiskopf et al., 2002; Davies, 2004; Ebi et al., 2004. The results of these studies are used in the following as a basis for discussing methodological issues related to social and economic assessment of the impacts of extreme heat events.

Changes in the probability of extreme heat can be measured in relation to various climate parameters such as maximum temperature, number of hot days, periods with high temperatures, as well as to relative changes in maximum temperature in relation to mean values. Patz et al. (2005) in a review of the impact of regional climate change on human health concluded that heat mortality follows a J-shaped function with a steeper slope at higher temperatures. It is important to recognize that the comfortable or safest temperature range vary with location, and are closely related to mean temperatures. The upper bound is as low as 16.5 °C for the Netherlands, and 19 C^0 for London but as high as 29 °C for Taiwan.

Simulations with the HIRHAM4 model by Koffi (2004) reveal that the climate at a given location in Europe might be as warm as the climate observed in the second half of the 20th century, but at 400-500 km South of that location. For instance, regions such as South-West France or Hungary in a future climate, may show a frequency of days above 30°C, as high as what was observed in the South of Spain or in Sicily during the 20th century.

In addition to this important geographical shift to the North of the number of hot days, a significant increase in the time period of occurrence is also expected. The maximum number of consecutive days above the threshold, which is a key factor of the human ability to cope with heat, also increases over the whole of Europe as illustrated in Figure 6. As an example, simulation results obtained for grid points near Paris show an increase from 9 to 50 of the mean annual number of days above 30 °C between the two periods. Whereas all such days for the 1961-90 reference period were confined to the summer period, only 89% of the total number of days above 30 ^{o}C occured between June and August for the period 2071-2100. The 30-yr average annual maximum number of consecutive days above 30 °C at that particular grid point increases from 3.5 to 18.9 days.

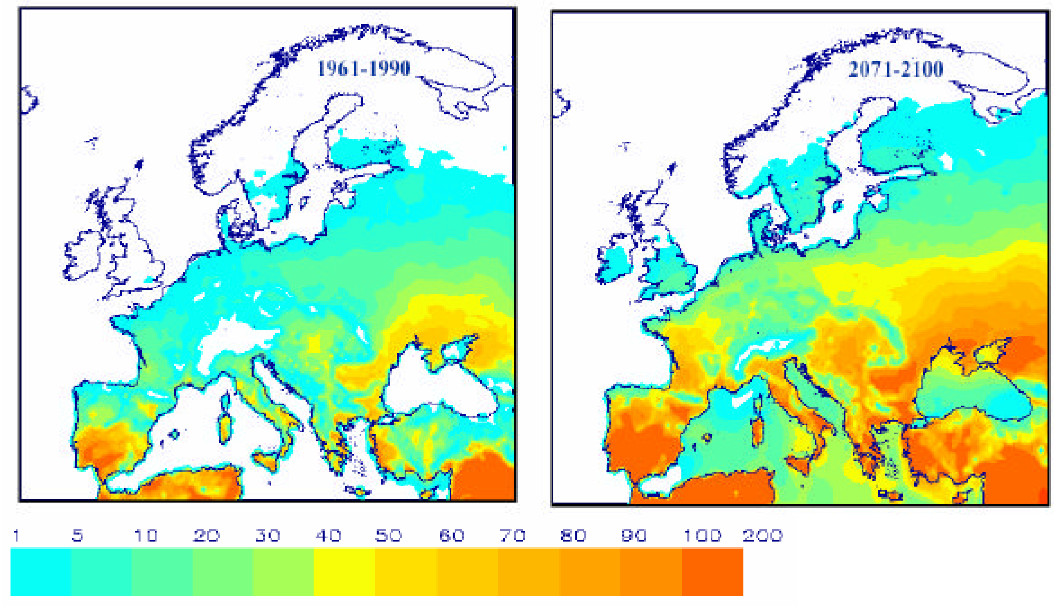


Figure 6 Mean Annual Number of Days Above 30°C Simulated by the HIRHAM4 Regional Climate Model for the 1961-1990 (Left) and 2071-2100 (Right) Periods.

Seen from a health perspective it is worth noticing that impacts of extreme heat waves due to climate change is a sub-set of the full range of climate related health impacts that according to Patz et al. (2000) include temperature related mortality and morbidity, and extreme weather events such as extreme cold, storms, tornados, hurricanes, and precipitation extremes. A recent study by McMichael et al. 2004 has estimated the total mortality attributable to climate change by 2000 and future development to 2030 (cited after Patz et al., 2005). The study indicates that climatic changes that have occurred since the mid 1970'es could already have caused 150,000 deaths globally per year. It is expected that this mortality will more than double by 2030. Excess mortality from extreme heat has not been included in these global studies due to uncertainty related to the regional and urban area time specific temperature data that is needed for such studies. However, it is worth recognizing that the number of reported deaths in Europe in the summer 2003 is significant seen in relation to the total climate change impact estimates.

Studies by Patz et al. (2000, 2005), Davies et al. (2003) and WHO (2004) have identified a number of climatic data that are important to the assessment of over mortality induced by extreme heat. The data include:

- Measures of temperature and humidity, e.g. heat index or air-mass condition.
- Measures of the relative change in temperature in hot periods over time relative to normal average temperatures[3].

[3] Health impacts tend to relate to the relative change in temperature in hot periods rather than the absolute temperature level, because people tend to react strongest to warm weather, when they are not used to it (Patz et al., 2000 p. 6, and Patz et al., 2005).

- Timing of the high temperature development over a given period[4].
- Urban and rural settlement structure, in particular for urban areas, where the heat have difficulties to escape during night time.
- Occurrence of accommodation without access to air-conditioning.

Based on the conclusions of these impact studies, regional and urban climate projections should provide information about the variance (scale) of temperature distributions during summertime, the development over short time periods during the summer, and on the structure of the temperature distributions. This information should be linked to detailed geographical information about urban settlements and to population statistics with information about health conditions, and groups at risk as for example including poor people, the elderly, and children, and people living in houses without access to air conditioning. Finally, more health specific information of importance includes health care access and social networks.

A major purpose of undertaking detailed assessments of heat wave induced illness and death is to be able to identify and assess adaptation options. Potential adaptation options include:

1. Air conditioning and fans.
2. Changed building construction and insulation systems, where buildings are constructed to avoid overheating from high temperatures.
3. Improved information implying that individuals can better compensate for the heat through fluid intake and altered activity patterns during day and night time.
4. Community wide heat emergency plans including heat warning systems and illness management plans.
5. General improvements in health care and the health conditions of the population.
6. Urban planning measures that facilitate cooling of urban areas during night time.

The social costs of heat waves and the benefits of adaptation can be assessed with a similar approach as suggested by Antle (1996). The welfare assessment can include the following steps:

- Assessment of the expected number of additional deaths caused by heat waves, EM in a given area.
- Selection of an approach for assigning welfare values to mortality, for example based on the Statistical Value of Life (SVL) approach.
- Calculation of the total welfare loss of the over mortality as $EM * SVL = TC_c$.
- Calculation of the cost of implementing alternative adaptation measures as the ones listed in items 1-6 above, AC.
- Assessment of the expected over-mortality compared with a non-climate change scenario given the implementation of adaptation measures 1-6, AM.
- Calculation of the economic loss associated with AM as $TC_A = AM * SVL$
- Calculation of the adjusted welfare loss of extreme heating arriving from climate change as $ATC = TC_A + AC$

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[4] People tend to react stronger to high temperatures early in summer periods, when they have not yet adapted to warmer weather.

Some of the elements in this cost assessment are relatively straightforward to cover, like for example assessing the costs of adaptation measures like building insulation, air conditioning, information programmes and heat emergency plans. Other elements, as for example urban planning measures and the benefits of general health care improvements, are more difficult to cover.

Ebi et al. (2004) estimated the costs and benefits of introducing a heat watch/warning system in Philadephia and compared the cost of a warning system with the benefits in terms of reduced mortality during heat events in 1993 and 1994 and in the 1995-1999 period where warning systems were introduced. The results suggest that the warning system lowered the daily mortality by about 2.6 lives on average[5]. The warning system that was introduced included various options including information, heatline and emergency medical service, and the costs of these options all together were assessed to be relatively low and only amounted to about $ 210,000 for the three year period in Philadephia. However, the benefits of the system were estimated be as high as in the order of $468 mill. (117 lives saved). The assumptions that are applied to estimations of the value of stastical lives are very critical to these results and will be discussed below. However, the major conclusion from the study of Elbi et al. (2004) is that the very low cost of heat warning systems make them very attractive, which have also been confirmed by studies of Weiskopf et al. (2002) and Kalkstein (2002) (cf. WHO, 2004).

A crucial issue in the welfare estimation is obviously the assignment of economic values to the loss of human life. These values can both reflect a general uniform value of lost lives for all individuals and can also take the remaining lifetime of the persons into consideration, which will suggest a lower value for elderly that also are the most vulnerable to extreme heat. This issue is extensively discussed among economists and other experts, see for example a brief summary of the discussion in IPCC (2001b, Section 7.4.4.2). Despite difficulties in valuing loss of human life, the issue is difficult to neglect since it plays a key role in studies of the welfare implications of climate change.

The quoted studies about costs and benefits of over-mortality related to extreme heat have used different estimates for the value of life. Ebi et al. (2004) assumed a statistical value of life of $ 6.12 mill and adjusted this value down to $ 4 mill. to take the relative high age of the affected into consideration. Studies for Europe that are reported by Markandya (1998) have assessed the Statistical Value of Life in Europe to be 3.14 mill 1995 ECU.

An impression about the scale of the social impacts of over-mortality due to heat waves can be provided by making a simple assessment of the costs of the previously reported European data of 18,000 people dying in the summer of 2003. Assuming for example a value of life lost of $ 4 mill. per person implies that the potential benefit of avoiding death from the European 2003 heat wave would been in the a maximum of

[5] Assuming that there was no displacement of mortality.

around $ 72 bill. Based on available studies, the costs of heat warning systems seem to be low compared with this estimated benefit.

Other adaptation measures to extreme heat such as air conditioning have been assessed by Davies et al. (2003). The study includes a specific reference to data on the relationship between access to air conditioning and over mortality, which clearly indicates the role this adaptive measure.

Conclusions

The economic and social consequences of climate change impacts have been assessed by linking detailed PRUDENCE climate model outputs to detailed farm management and health data in two case studies namely a Danish example on wheat management conditions, and a central European example on excess mortality from heat waves. These cases illustrate that the consequences of given changes in climate parameters depend on a complex interaction between socio-economic development trends, technological change, production management practices, urban settlement structures, lifestyles, and on adaptation measures related to information about climate variability, farm management, new crops, air conditioning systems and health care systems.

An econometric model that links farm data and climate data has been applied to an assessment of climate change impacts on wheat yields in Denmark taking present and future monthly temperature and precipitation data into consideration, and it was concluded that average wheat yield will decrease significantly with future climate change in the 70 years timeframe of the Prudence projections. However, the production efficiency at the same time is expected to increase due to technological change, and the net impact of climate change taking technological change into consideration in sensitivity analysis suggests that there most likely is a slower growth in wheat yields than without climate change, but not an absolute decrease compared with the levels of today.

In reality it is very difficult to project technological change over so long time horizons, and it is even more complex to be able to integrate adaptation measures as a response to climate change. Such adaptations include changes in sowing date (Olesen, 2005), increased use of plant protection agents, irrigation and improved varieties, in particular varieties with a longer duration of the grain filling period. However, there is limited information on the effectiveness of such adaptation options to reduce the negative effect of increasing temperature (Alexandrov, 2002; Ghaffari et al., 2002).

Wheat yield will also be influenced by a number of other indirect impacts from climate change including biomass growth benefits from increased atmospheric CO_2 concentrations and losses from increased insect pests and diseases implying increased production costs and lower outputs. Primarily, the CO_2 fertilization impact is not captured in the model, and the exclusion of this tends to decrease the estimated yields significantly, and thus may more than outweigh the direct impact of future climate change in Denmark.

The climate change projections show that the European climate in the last part of this century may be significantly warmer than today, and the frequency of very warm days will increase. Based on this result an approach for assessing the costs and health impacts of excess mortality due to extreme heat has been outlined and the results of studies about the costs of adaptation options versus the benefits of reduced over-mortality during extreme heat periods are reported. The studies have show that the climate information should be transformed into indexes of heat and humidity, relative temperature changes, and should be linked to detailed demographical data and urban settlement structures with information about the building stock, air condition, and access to health services.

A number of potential adaptation options have been identified including air conditioning, information to individuals about heat coping strategies, health emergency plans, changed building construction and insulation systems, and urban planning measures that facilitate cooling of urban areas during night time. A number of studies for US cities show that the costs of establishing heat warning systems have shown up to very low compared with the benefits in terms of lives saved. Empirical studies have also suggested that the implementation of improved air conditioning can be expected to imply substantial reductions in excess mortality from extreme heat, so it is worth conduction more detailed assessments and to plan adaptation options in order to mitigate future health impacts from climate change. This should also be seen in relation to the high expected benefits that can be associated with reduced mortality. Based on a study of the Statistical Value of Life for Europe is has been estimated that avoiding the about 18,000 human lives lost during the heat wave in Europe in the summer of 2003 could have rendered benefits as large as $ 72 bill.

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