Institut für Volkswirtschaftslehre

Universität Augsburg

Volkswirtschaftliche Diskussionsreihe

Land Prices and Climate Conditions
Evaluating the Greenhouse Damage
for the German Agricultural Sector

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Beitrag Nr. 233, January 2003

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Abstract

Using an exhaustive panel dataset of the German agricultural sector, this paper is evaluating the relationship between climate conditions and land prices. The main advantage of this so-called hedonic approach is the consideration of the full range of adaptation options to the climatic environment. A Box-Cox form is employed to allow for very flexible relationships between land prices, warmth, moisture, and different socioeconomic variables. In a second step, the estimated results are used to forecast the impact of global climate change on the farming sector. The results show that a change of the temperature level has stronger impacts than a change of rainfall. Using a greenhouse warming scenario, German farmers are expected to be winners of climate change at least in the short run. Maximum gains are estimated with a temperature increase of +1.0°C against the current levels. Should the temperature increase surpass 1.8°C, however, the impact on the farming sector is clearly negative.

JEL classification:

Q12, Q25

Keywords:

Agriculture; farming land; hedonic approach; climate change; environmental valuation; global warming; impact study

Acknowledgement:

I'm indebted to the German federal ministry of agriculture and the German weather service for supporting this study and for providing the data set.

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Introduction

Is the Earth's climate changing, and which are the consequences for natural and human systems? Even the skeptical minority, claiming that climate change does not occur or is not induced by human activities, agrees to the high relevance of these questions. The answer of the Working Group I of the IPCC on the first question is an unequivocally "Yes". Over the last century, their best estimate is that global average surface temperature has already increased by 0.6°C. Although future projections have been revised downwards from former estimations, the expected minimum warming is 1.4°C over the period to 2100. Due to increasing water evaporation, precipitation levels are also projected to increase. The scenarios for Europe clearly show that the expected warming over Northern Europe is above average warming in the winter months, over Southern Europe in the summer months (*IPCC 2001a*).

As for the question on the most probable consequences for natural and human systems, the Working Group II finds a broad range of physical, biological and human systems affected to climate change (*IPCC 2001b*). Due to a critical dependence on moisture and warmth, agriculture is one of the most affected sectors. For example, according to *Cline (1992)*, for the US the damages in agriculture overtake those from the energy sector by more than 50%, those from sea level rise by 150%. From their exhaustive literature analysis, *Pearce et al. (1996)* conclude that globally about one fifth of all damages will occur in agriculture.

This study attempts to evaluate the impacts of climate change on the second largest food producer in Western Europe, Germany. As in contrast especially to the US (see e.g. *Adams et al, 1998, Brown and Rosenberg, 1999, Mendelsohn et al., 1994, Dixon et al., 1994*), only a few papers are available for European countries. Although some studies have assessed the impacts of global warming on an European-wide scale (see *Kundzewicz and Parry, 2001, pp. 667f.*, for an overview), relatively little work has been done for specific countries with their own socioeconomic and climatic microstructures (see e.g. *Maddison, 2000*, for the UK, or *Lang, 2001*, for Germany). Considering the high output shares for some basic products[2], the very differentiated climatic conditions in Germany[3], and the broad range of soil qualities, this lack of scientific interest is somewhat surprising.

To measure the relationship between climate conditions and farming, at least four different approaches can be used: Greenhouse experimental studies (see e.g. *Strain and Cure, 1985*), plant growth simulation models (e.g. *Wolf, 2002*), black-box regression models (e.g. *Kaylen et al., 1994*), and hedonic methods (e.g. *Maddison, 2000*). This study follows the hedonic approach which has been made popular for impact studies by *Mendelsohn et al. (1994)*[4]. Hedonic papers attempt to value the non-monetary components of market decisions. Examples are the relevance of working conditions for the wage rate, or the relationship between the characteristics of a particular location (e.g. noise pollution, public infrastructure) and home prices at that location. By quantifying these links, the hedonic approach allows for an economic valuation of non-traded goods.

This idea can also be used to determine the shadow values of temperature, precipitation, or other climate characteristics. As the hedonic approach states, the price signals of the input factor land contain information about all productivity relevant characteristics and therefore (also) on regional climate. In contrast to approaches relying on simulation models for plant growth, the hedonic method allows for a full adaptation of the farmers to an exogenous environment without explicitly modeling this process of adaptation. Examples for adaptation are the selection of plants and livestock, or a switch from grain

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[2] For example, Germany is the largest EU-producer of milk (24% share) and pork (22% share), and takes the second rank in grain (22%), sugar (24%) or beef (19%).

[3] Even when limiting the analysis to cultivated land, annual mean temperatures is in a wide range from 6.5°C to 12°C. Similarly, annual rainfall is varying between 450 mm and 1500 mm per year.

[4] Actually, *Mendelsohn et al. (1994)* called their theoretical background “Ricardian approach”. Since the differences are marginal, in the following the more general term “hedonic approach” is used.

to other products like vegetables or grassland. In a second step, this information can be used for estimating the impact of the greenhouse effect given the full range of available adaptation options. Although the relevance of adaptation as a response to climate change is well known (*Fankhauser et al., 1999*), most damage studies assume little or no adaptation.

The structure of this paper is as follows: In a first step, the theory of hedonic prices as well as the estimation process is described. Chapter 3 gives an overview over the data used for the empirical application. The main results of the estimations are provided in chapter 4. Finally, chapter 5 rounds up by a short conclusion.

Theory of Hedonic Prices

In the focus of the hedonic approach are the price determinants of a differentiated consumer product or of a differentiated factor of production. The observed prices of differentiated inputs may vary considerably due to a causality between input characteristics and productivity. Labor is a prominent example for different input characteristics. When analyzing the agricultural sector, the input factor land with its widely varying productivity structures is a natural choice. Following *Palmquist (1989)*, the rental price of farming land r depends on a vector of exogenous characteristics z:

$$r = r(z) \tag{1}$$

Equation (1) is called the hedonic price function for land, describing this relationship between land prices and land characteristics z. The vector z may consist of soil quality, regional infrastructure, slope of a certain piece of land, and climate variables like temperature or precipitation. To derive the willingness to pay for any change z, land is explicitly separated from the profit function π of the farmer:

$$\left.\begin{aligned} &\max \pi = \sum_{i=1}^{m} p_i y_i - rL \\ &s.t. \quad F(y,z) = 0 \end{aligned}\right\} \pi^* = \sum_{i=1}^{m} p_i y_i^*(p,z) - rL \qquad (2)$$

In equation (2), L represents the given amount of land used to produce different outputs. The quantities y_i and the corresponding prices p_i describe m nonland-netputs of the firm, i.e. all outputs and all variable inputs excluding farmland. Technological restrictions are considered by the transformation function $F(y,z)$, which describes the efficient production function (*Chambers 1988, 260 f*). $F(y,z)$ may represent a one-output-world as well as a multi-output-world, with z being an important determinant of firm productivity.

As a conclusion from equation (2), two channels of different land qualities to influence the behavior of farmers can be identified: First, via the impact of z on the technology frontier, and, second, via the land price r. Maximization of the profit subject to the transformation function and exogenous netput prices yields m demand respectively supply equations y_i^*.

From (2), the maximum willingness to pay for one unit of land θ is

$$\theta = \theta(p,z,\tilde{\pi},L) = \frac{\sum_{i=1}^{m} p_i y_i^*(p,z) - \tilde{\pi}}{L}. \qquad (3)$$

Therefore, to identify the true relationship between land prices and the z-variables, it is necessary to control for the different price and profit levels ($\tilde{\pi}$) of the firms. A direct estimation of the hedonic price function (1) would result in biased results since important determinants of observed land prices are not considered. $\tilde{\pi}$ can be interpreted as "desired profit level" (*Palmquist, 1991, p. 83*) and is equal to zero for a perfect competitive world.

Equation (3) can be used to estimate the shadow prices of the non-traded z-variables. By partially differentiating this bid-function with respect to the single components of land-quality, one gets the change in profit induced by a marginal increase of the corresponding z-variable:

$$s_k = \frac{\partial\theta(p, z, \tilde{\pi}, L)}{\partial z_k} \quad k = 1, \ldots, q. \tag{4}$$

The shadow price s_k can be interpreted as the inverse of the demand function for the specific characteristics z_k (*Palmquist, 1989*).

To monetary value the impact of an environmental change, the bids for land under two climate regimes have to be compared:

$$s^{z^0 z^1} = \theta(p, z^1, \tilde{\pi}, L) - \theta(p, z^0, \tilde{\pi}, L) \tag{5}$$

$s^{z^0 z^1}$ shows the difference in land prices given a change in land characteristics from z^0 to z^1. Of course, this change in z is not restricted to one single component, but may occur simultaneously over the whole z-vector. For example, global climate change will have effects on temperature, precipitation, weather extrema etc. Differences in θ due to this change in z indicate a different willingness to pay for certain z-environments. Shadow values are not restricted to a certain sign, but can be positive („public good") as well as a negative („public bad"). Slight modifications of (5) allow for the monetary valuation of the change in just one single climate variable or of the relationship between simultaneous changes in p and in z. The latter could be of interest if global warming reduces world food supply and increases food prices (*Kane et al., 1992*).

Although theoretical considerations do not dictate a specific functional form for the bid equation, a highly flexible functional form is superior to more simple forms due to their high adaptation capabilities. Therefore, following *Halvorsen and Pollakowski (1981)*, the quadratic Box-Cox (QBC) as one of the most flexible forms used in empirical work is employed. Suppressing firm and time indices and stacking netput prices p as well as land characteristics z into one vector x, the Box-Cox function can be written as

$$\theta^{(\rho)} = \alpha_0 + \sum_{i=1}^{n} \alpha_i x_i^{(\lambda)} + \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} x_i^{(\lambda)} x_j^{(\lambda)} , \quad (\gamma_{ij} = \gamma_{ji}) \tag{6}$$

where

$$\theta^{(\rho)} = \begin{cases} \dfrac{\theta^{2\rho} - 1}{2\rho} & \text{if } \rho \neq 0 \\ \ln\theta & \text{if } \rho = 0 \end{cases}$$

$$x^{(\lambda)} = \begin{cases} \dfrac{x^{\lambda} - 1}{\lambda} & \text{if } \lambda \neq 0 \\ \ln x & \text{if } \lambda = 0 \end{cases} . \tag{7}$$

$$n = q + m$$

The high flexibility of the quadratic Box-Cox can immediately be recognized from some special cases of this function, which include – among others – the log-linear, the generalized Leontief, the generalized square root quadratic and the Translog function. *Table A- 2* in the appendix shows the necessary restrictions on the QBC to receive these traditional forms. Therefore, by using e.g. Likelihood-Ratio tests, the QBC is an appropriate instrument for the statistical discrimination between different functional forms.

Although the dataset of this study is quite exhaustive, the number of free parameters had to be somewhat reduced, however. Actually, the full QBC is described by $3 + n + n(n+1)/2$ parameters, summing up to 68 free parameters for the data of this study ($q = 3; m = 7$). To guarantee a stable optimization process, the interaction terms γ_{ij} are set for the climate variables warmth and moisture, which are in the focus of this paper, but not for the netput prices. This procedure is in line with the findings of *Crop-*

per et al. (1988), who suggests a linear Box-Cox specification (i.e. without interaction terms) in the case of problems with the estimation procedure.

The parameters are estimated by maximizing the concentrated log-likelihood function (*Ornelas et al., 1994*)

$$\ln L_C(\beta,\rho,\lambda) = -\frac{N}{2}(\ln(2\pi)+1) + (2\rho-1)\sum_{t=1}^{N}\ln\theta_t - \frac{N}{2}\ln\sum_{i=1}^{N}\frac{\varepsilon_i^2}{N} \qquad (8)$$

where N is the number of observations, β is the parameter vector compatible to x, and ε is the corresponding error term assumed to be normal distributed. Standard errors of the parameters are determined by calculating the inverse of the cross-products of the first derivatives.

One powerful implication of a flexible functional form is that analytical simplification tests can easily be conducted. Aside from tests on the appropriate functional specification (*Table A- 2*), the relationship between climate conditions and land prices is in the focus of this paper. Assuming that the indices $i = 1,2$ represent the climate variables warmth and moisture, the following hypotheses are conducted on the basis of equation (6):

Hypothesis i)

The climate environment is without any relevance for land prices. Necessary restrictions for a test of this basic question are

$$\alpha_1 = \alpha_2 = 0 \quad \text{and} \quad \gamma_{ij} = 0 \quad i, j =,2\,. \qquad (9)$$

Hypothesis ii)

Temperature doesn't matter:

$$\alpha_1 = 0 \quad and \quad \gamma_{11} = \gamma_{12} = 0\,. \qquad (10)$$

Hypothesis iii)

Precipitation doesn't matter:

$$\alpha_2 = 0 \quad and \quad \gamma_{12} = \gamma_{22} = 0\,. \qquad (11)$$

Hypothesis iv)

To round up statistical tests on the bid equation, the relevance of netput prices is conducted by imposing zero-restrictions on those α – parameters which weight the netput prices.

The Data

The data used for estimation of the outlined model consist from two parts: Agroeconomic variables measuring land prices, other netput prices, land quality, and farm profits, and – second – real weather data representing the current micro climate. All agroeconomic data was obtained from the German federal ministry for agriculture, supplemented by weather data from the German weather service. As for the simulation of climate change, the scenarios of the ACACIA-IPCC project are used (*Kundzewicz and Parry 2001*, 649 ff.). Based on a selection of the best performing climate models, country-specific projections are made for future temperature and precipitation. Changes in mean climates are projected for the near future (the 2020s), the 2050s, and the far future (2080).

Information about the agroeconomic variables are available for five different types of farmers, which are again subdivided into 41 regions (see *Figure A- 1* in the appendix for the geographical demarcation). The five types represent different kinds of specialization like fattening or the production of vegetables and fruit. For each region and each specialization, information about a representative farmer is given. All data is available in a panel style with an observation length of five periods (1990 to 1994). Due to the fact that some kinds of specialization do not exist in certain regions, the actual number of observations is 803 and therefore somewhat lower than the theoretical maximum of 1025 observations (41 regions, 5 specializations, 5 years).

Land prices r are measured as per hectare rents to be paid in a particular region. To account for differences in land quality aside from climate characteristics, the granted subsidy on land for farmers in “disadvantaged regions” is used. This payment is a quite good indicator for land quality since its main determinant is the slope of a particular piece of farming land. As for the netputs other than land, one input and six outputs are identified. The detailed break down on the output side is motivated by the assumption of a strong relationship between product selection and climate condition. To be more specific, outputs are differentiated into crops, sugar beet, potatoes, oilseed, the product group vegetables/fruits/wine, and – finally – animal output. The input price is calculated as the cost-share weighted mean of the labor, capital and material price. Following the proposal of the ministry for agriculture, the labor price of the mainly self-employed farmers is based on the concept of opportunity costs. As for the price of capital, the depreciation rate as well as all opportunity costs are considered (user-cost of capital). All input prices are considering factor specific subsidies, all output prices are taking product specific subsidies into account. Profits, which are necessary to calculate the bids θ (see equation (3)), are defined as the difference between total revenues and total cost, the latter including land expenses.[5] *Table 1* presents detailed information about the seven netputs.

Climate data for the observation period is available from weather stations in Western Germany. Since some of the weather stations are not relevant for agricultural production, in a first step all irrelevant stations (i.e. on mountain tops) are deleted. For the remaining 75 stations, the available information is condensed to two climate variables, which are relevant for crop growth: a) Effective temperature sum (*ETS*) as an indicator for the thermal situation, and b) the Thornthwaite's moisture index (*MI*) as an indicator for the availability of moisture. ETS is summing up the degree Celsius exceeding 5°C over one year, which is a threshold for plant activity. Formally,

$$ETS = \sum_{t=January}^{December} d_t \cdot \min\{(°C_t - 5); 0\}, \qquad (12)$$

where $°C$ is the monthly mean temperature and d_t is the number of days of the corresponding month.

Regional moisture conditions are calculated as the ratio between precipitation $PREC$ and (potential) evaporation PEV:

[5] Negative profits are assumed to be temporary and are substituted by a zero value.

$$MI = 100 \cdot \sum_{t=January}^{December} \frac{PREC_t}{PEV_t}, \qquad (13)$$

Given a certain level of precipitation, the available moisture is as higher as lower is the temperature since temperature is the main factor driving evaporation (see *Thornthwaite, 1948*, for the calculation of potential evaporation).

Finally, in order to link the agroeconomic information which is organized by 41 regions and the climate data which is available for 75 stations, an assignment following the principle of spatial proximity is conducted. If more than one station is found relevant for a particular agricultural region, the mean value is used.

As a possible scenario for climate change, the projections of the *ACACIA-IPCC* model are adopted. For Germany, an average temperature increase in the order of 0.9°C is expected until the year 2020. In the longer term, the warming will grow to about 1.6°C in 2050 and 2.2°C in 2080, respectively. As for precipitation, the models show no clear positive or negative trend. To maintain the regional heterogeneity of climate, all differences between the current and the future climate are added to every weather station (*Smith and Tirpak, 1990*). In a second step, the scenarios are translated into meaningful *ETS* and *MI* values. As can be seen from *Table 1*, where information about the current climate as well as about the mid-term climate change scenario is provided, the moisture index will decrease in spite of the unchanged precipitation. This result is the consequence of higher evaporation due to increasing surface temperatures.

Table 1: Statistical information on the data

	description	Mean	std. dev.	min	max
Land price	gross rent per year, €/ha	259.5	231.8	23.1	4455.0
		Land characteristics			
Current climate	*ETS* (effective temperature sum)	1924.2	239.8	1370.0	2683.9
	MI (moisture index)	122.6	37.2	52.4	313.0
Land quality	*DIS* (public subsidy for disadvantaged regions, €/ha)	24.7	25.6	0.0	147.1
Future climate (IPCC)	*ETS* (year 2050)	2381.4	275.7	1756.1	3246.3
	MI (year 2050)	112.8	36.7	43.6	301.1
		Netput prices			
Input price	inputs other than land (index)	101.3	8.1	78.2	153.9
Output prices	crops (index)	96.0	9.6	69.2	161.8
	sugar beet (index)	101.7	9.0	72.4	139.4
	potatoes (index)	107.3	43.5	45.4	472.6
	oilseed (index)	91.0	9.7	64.1	217.3
	vegetables, fruit, wine (index)	84.4	14.5	64.8	108.5
	animal output (index)	94.9	8.8	74.7	153.2
Profit	yearly profits, €/ha	152.7	362.0	0.0	4252.4

Number of observations: 803.
Land rent, prices and profits in 1990-values.
Price indices are scaled so that the mean value over all farmers in the corresponding price group is 100 in 1990.

Empirical Results

Parameter estimates for the bid function (6) were generated by numerically maximizing the likelihood function (8). The corresponding program code is written in GAUSS. To test for the robustness of the results, two versions of the model are estimated: Model I which tries to explain the profit-corrected land rents, and model II, where gross land rents are used. By imposing the symmetry restriction on the interaction parameters of the quadratic B-C form, 803 observations are available for the determination of 16 free parameters. As can be seen from *Table A- 1*, where the estimation results are presented, about 60% of the single parameters exhibit a significance level of at least 90%. The determination coefficient stands at 0.39 for model I and 0.37 for model II, which is quite satisfactory for a micro analysis.

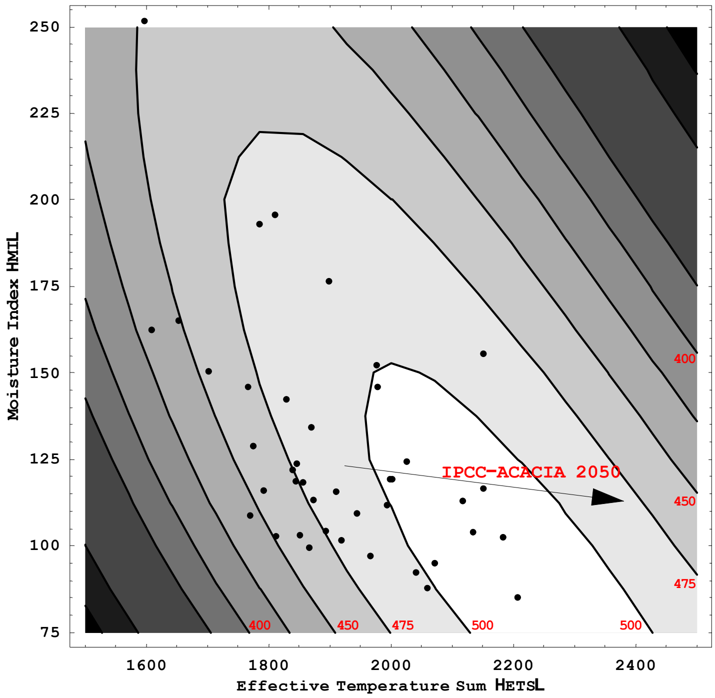
Table 2: Likelihood-ratio-tests on simplified model structures

hypothesis	degrees of freedom	$\chi^2_{0.95}$	Model I: λ_{LR}	Model II: λ_{LR}	Conclusion
i) climate conditions are irrelevant	5	11.1	16.8	13.5	Reject
ii) temperature doesn't matter	3	7.8	16.4	13.4	Reject
iii) moisture doesn't matter	3	7.8	4.8	8.0	Depends on model
iv) netput prices don't matter	7	14.1	111.0	52.9	Reject
v) linear specification is adequate	5	11.1	1515.0	1398.0	Reject
vi) Translog specification is adequate	2	6.0	143.2	72.8	Reject
vii) linear Box-Cox is adequate ($\gamma_{ij} = 0$)	3	7.8	8.4	13.4	Reject

λ_{LR} is value of the likelihood-ratio statistics; χ^2 gives the critical values.

To begin with a statistical analysis of the results, likelihood-ratio tests were run to check over the functional form and over the relevance of the climate variables. Test values are generated by re-estimating function (6) with additional restrictions. The results, given in *Table 2*, clearly show the advantage of the quadratic B-C form against the more simple forms: Even the linear B-C performs significantly worse than the quadratic B-C. All traditional functional forms like the translog, the linear or the loglinear form (not shown) are significantly rejected. Similarly, with the exception of hypothesis iii), the impact of climate conditions on land prices can be considered as sure. Both models show the (statistically) more important role of the thermal situation on the willingness to pay in comparison to the availability of moisture. Due to the somewhat higher explanatory power of model I, in the following only the conclusions from model I are presented.[6]

Figure 1: Temperature, moisture, and land prices



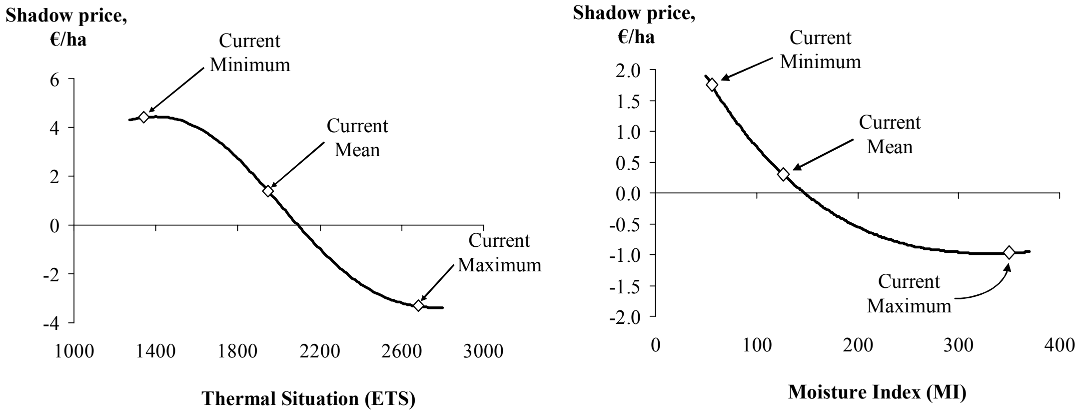
Dots represent the current position of 41 agricultural regions. Contour values are in €/ha. Illustration based on model I.

[6] Actually, the implications of both models are very similar.

For an economic interpretation of the parameter estimates, in a first step the relationship between the willingness to pay for land and climate conditions is illustrated. To focus on pure productivity effects of climate, average netput prices are taken for the evaluation of land prices. *Figure 1* visualizes the result of these calculations for a broad range of *ETS-MI* combinations, using a map of land price contours. Each contour represents a 25€/ha difference. The highest willingness to pay appears for *ETS*-values of about 2200 (~10.5°C year mean temperature) in conjunction with a moisture index of about 100 (~800 mm precipitation per year). Given this combination of the climate environment, farmers would agree to pay up to 500€ per hectare per year. From the actual position of the particular regions the conclusion can be drawn that the majority of the German farmers currently suffers from a somewhat too cold climate. A small move to the right would therefore increase the willingness to pay. However, as can be seen from the arrow in *Figure 1*, which represents the expected movement of each individual position due to climate change, the temperature increase is frequently beyond the optimal level.

Based on equation (4), the shadow prices of the climate variables are plotted in *Figure 2*. As intuitively expected, a negative relationship between the level of *ETS* and the shadow price for a additional warmth can be observed. The plot also shows that warming as a marginal effect would benefit the representative farmer, thus confirming the findings from *Figure 1*. Similarly to temperature effects, a negative relationship is evaluated for the availability of moisture and the shadow price of additional moisture, too.

Figure 2: Shadow price of temperature and rainfall



All calculations for a representative farmer and current netput prices.
The shadow value indicates the change in the willingness to pay for one ha of land given an increase in ETS or MI, respectively, by one unit.
Illustration based on model I.

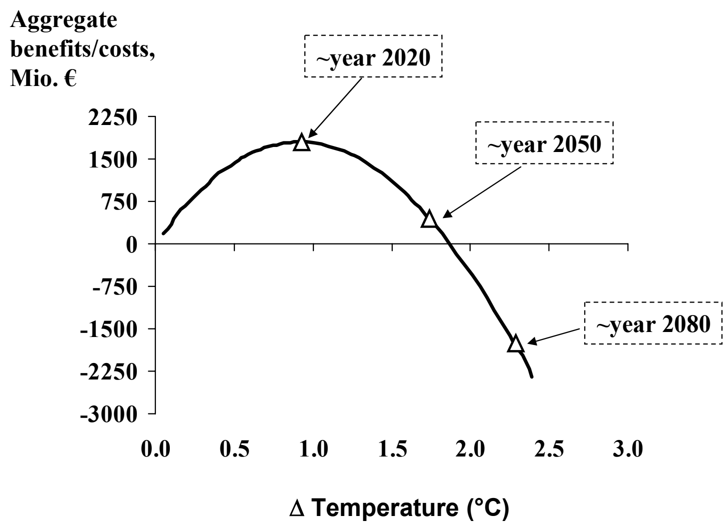
Global warming will not be limited to a marginal change of temperature or precipitation, however. For Germany, the change in temperature is expected to be at least as high as global average warming. To capture for the time table of global warming, simulations were run using the ACACIA scenarios up to the year 2080.[7] *Figure 3* shows the results of these simulations, where regional projections are aggregated to the national level. This aggregation is done by multiplying regional per-hectare-results with the weight of the particular region.

The results indicate that the German agricultural sector will be among the winners of global warming – at least in short run. Maximum benefits are estimated to be about 2 bn €, which is 5%-6% of the current production value. However, if temperature should increase by more than 1°C, which is very probable in the long run, benefits will shrink and even reverse negative. This threshold is estimated to be at about +1.8°C. Following the scenarios of the IPCC-ACACIA project (*Kundzewicz and Parry, 2001*), this critical

[7] Using a longer time horizon doesn't make sense since temperature increases beyond 2.5°C are not covered by the current heterogeneity of climate conditions.

value will be reached somewhat later than 2050. Due to the concave shape of the benefit curve, losses will increase fast beyond that level of warming. However, compared to the US, where most studies (see e.g. *Cline, 1992, Mendelsohn et al., 1994, Pearce et al., 1996, Smith and Tirpak, 1990)* show a strong negative to a slightly positive impact (-12% to +1%), the German agricultural sector turns out to be more positive affected.

Figure 3: A transient global warming scenario and its impact



Simulation based on model I; time schedule from IPCC-ACACIA.
All variables other than temperature on current level.
Benefits/costs in 1990-prices.

Aside from the aggregate impact, distributional aspects are also worth to be discussed. Actually, the very differentiated climate structures will create winners and losers from greenhouse warming. To demonstrate this result, the land price changes from the ACACIA-IPCC scenario 2050 are broken down to the regional level. Although the aggregate impact is near to zero, the estimations show that more than 40% of the agricultural area in Germany will be negatively affected. The decrease in prices for these land areas is estimated at 42 € per hectare, which is significant given an average per hectare price of 260 €. Some regions will even suffer from a hectare price drop of more 40% compared to the current level. In contrast, the winners of climate change will enjoy an price increase of about 27 € per hectare. Details on the estimations are shown in Table 3.

Table 3: Distributional aspects of climate change

	Area (ha)	Share of total farmland	€/ha (mean value)	Profit/Loss
Losers	4.97 Mio	42.7%	-42 €	-207 Mio €
Winners	6.67 Mio	57.3%	27 €	179 Mio €
Sum	11.6 Mio	100%	-2 €	-28 Mio €

Calculations for model I.
Climate change scenario from ACACIA-IPCC for the year 2050.
Benefits/costs in 1990-prices.

Finally, as *Reilly and Hohman (1993)* state, in addition to the pure productivity effects all global market changes have to be considered as well. Because of an inelastic demand, the relationship between climate and world prices may even be more important than the productivity effect. Due to a negative impact of climate change on agriculture on the global level, food prices will most probably increase. As for Germany, where productivity is expected to increase in the short run, farmers will make additional gains from increasing world market prices. In the long run, when climate change is estimated to be negative for productivity, even a small price increase may easily offset the decline in productivity, however. Given the climate change scenario for 2050 as in Table 3, an output price increase by 25% – which is well within the forecasts of world market models (see *Kane et al., 1992*) – would raise the shadow value of global warming from -2€/ha to 170€/ha.

Conclusion

This study attempts to evaluate the impact of climate change on agricultural productivity and therefore on land prices in Germany, using the hedonic approach. The main advantage of this technique is the consideration of the full range of adaptation measures to the climatic environment. A Box-Cox form is employed to allow for very flexible relationships between land prices, warmth, moisture, and different socioeconomic variables like input and output prices. The empirical results indicate that the willingness to pay for land is more dependent upon warmth than upon moisture. Combining the estimation results with a global warming scenario, the German agricultural sector is found to significantly gain from a temperature increase. Maximum gains are estimated with a temperature increase of +1.0°C against the current levels. Should the temperature increase surpass 1.8°C, however, the impact on the farming sector is clearly negative. From the ACACIA-IPCC transient climate change scenario, negative territory will be reached at about 2050. In contrast to the aggregate impact, some regional impacts could be quite negative, however (a similar conclusion for the US was drawn by *Lewandrowski and Schimmelpfennig, 1999*).

It is important to note that no general conclusions on the impact of the increasing greenhouse effect should be drawn from this study. Global warming will affect all countries and many market and non-market sectors. Although the German farming sector is estimated to be a winner of global warming, the aggregate effect on a worldwide basis is probably negative. It may be the case, however, that with an appropriate consideration of adaptation options the enormous damages estimated by calibrated crop-yield studies on world agriculture have to be revisited downwards.

As for economic and agricultural policy, one should keep in mind that a) global warming will not stop at a particular point of time, and b) even in the short run significant damages may occur on a worldwide scale. As a minimum measure, farm sector flexibility to a changing environment should be further enhanced. For example, research could be conducted on crops that are better suited to perform well under the expected range of weather conditions. Given a high probability that the global mitigation strategy will fail, the immediate start of such time-intense programs is an important option for the future.

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Appendix

Figure A- 1: Spatial distribution of production areas and weather stations

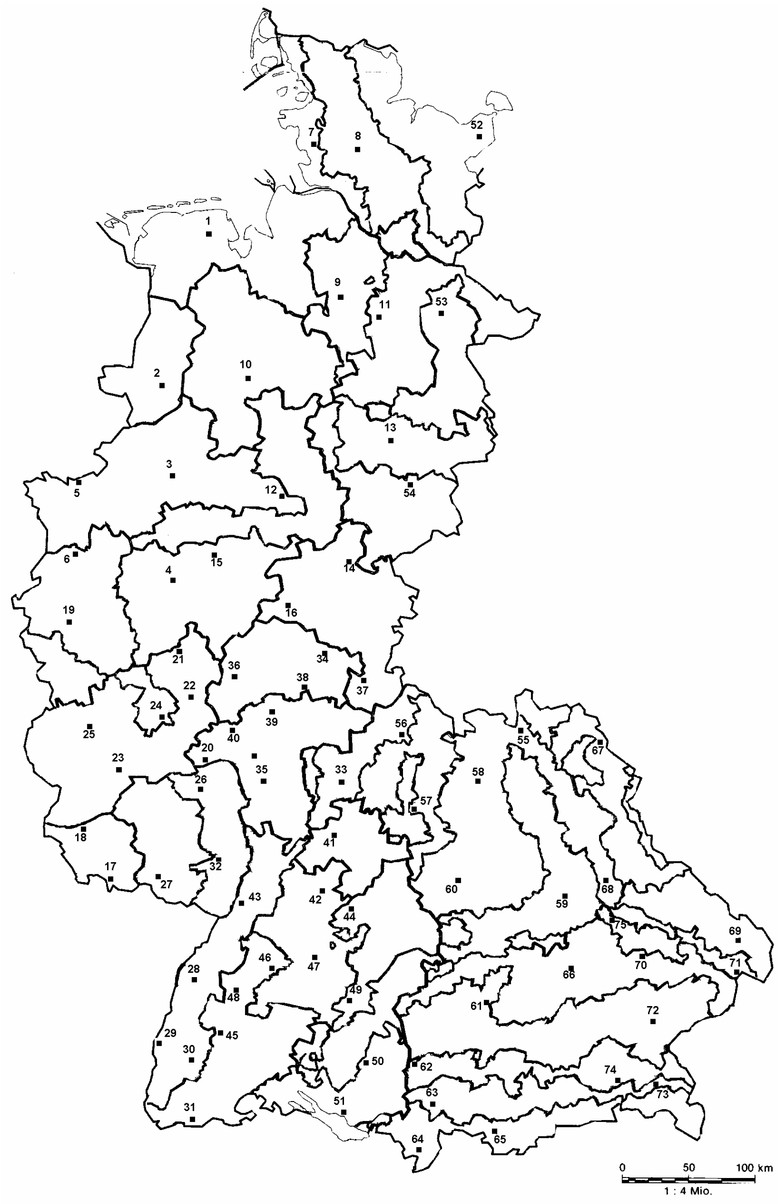

Table A- 1: Estimation results

	Model I		Model II	
	parameter	standard error	parameter	standard error
$const$	0.6002	0.972	-2.0931	2.068
$ets^{(\lambda)}$	0.1054	0.057*	0.3185	0.160 **
$mi^{(\lambda)}$	0.0303	0.023	0.1044	0.058 *
$dis^{(\lambda)}$	-0.0066	0.002*	-0.0129	0.003 *
$p_{input}^{(\lambda)}$	-0.0175	0.006***	-0.0102	0.005 *
$p_{crops}^{(\lambda)}$	0.0028	0.003	0.0151	0.006 **
$p_{sugar\ beet}^{(\lambda)}$	-0.0020	0.003	0.0076	0.006
$p_{potatoes}^{(\lambda)}$	-0.0025	0.001***	-0.0077	0.003 ***
$p_{oilseed}^{(\lambda)}$	-0.0050	0.003*	0.0018	0.005
$p_{vegetables}^{(\lambda)}$	0.0087	0.003***	0.0094	0.005 *
$p_{animal\ output}^{(\lambda)}$	0.0131	0.006***	-0.0032	0.009
$ets^{(\lambda)} \cdot ets^{(\lambda)}$	-0.0023	0.002	-0.0087	0.005
$ets^{(\lambda)} \cdot mi^{(\lambda)}$	-0.0006	0.001	-0.0030	0.002 *
$mi^{(\lambda)} \cdot mi^{(\lambda)}$	-0.0002	0.001	-0.0009	0.001
λ	0.59	0.069***	0.53	0.069 ***
ρ	-0.15	0.003***	-0.09	0.003 ***
$\ln L$	-4660.6		-4161.0	
R^2	0.394		0.374	
$observations$	803		803	

Model I: Explained variable is profit adjusted land rent $\theta^{(\rho)}$
Model II: Explained variable is gross land rent $r^{(\rho)}$
Asymptotic standard errors in parentheses. ***, ** and * denote a significance level of 99%, 95% and 90%, respectively (two-sided).

Transformation rules (for $\lambda, \rho \neq 0$):

$$\theta^{(\rho)} = \frac{\theta^{2\rho} - 1}{2\rho}$$

$$x^{(\lambda)} = \frac{x^{\lambda} - 1}{2\lambda}$$

Table A- 2: Specific cases of the quadratic Box-Cox form (QBC)

Description	**Functional form**	**Necessary restrictions on QBC**
Linear specification	$\theta = \alpha_0 + \sum_{i=1}^{n} \alpha_i x_i$	$\rho = 0{,}5$ $\lambda = 1$ $\gamma_{ij} = 0$ $(i, j = 1, \ldots, n)$
Log-linear specification	$\ln\theta = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln x_i$	$\rho = \lambda = 0$ $\gamma_{ij} = 0$ $(i, j = 1, \ldots, n)$
Translog	$\ln\theta =$ $\alpha_0 + \sum_{i=1}^{n} \alpha_i \ln x_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln x_i \ln x_i$	$\rho = \lambda = 0$
Generalized Leontief	$\theta = \alpha_0 + \sum_{i=1}^{n} \alpha_i x_i^{\frac{1}{2}} + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} x_i^{\frac{1}{2}} x_j^{\frac{1}{2}}$	$\rho = \lambda = 0.5$
Normalized Quadratic	$\theta = \alpha_0 + \sum_{i=1}^{n} \alpha_i x_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} x_i x_j$	$\rho = 0.5$ $\lambda = 1$
Square-rooted Quadratic	$\theta = \left(\alpha_0 + 2\sum_{i=1}^{n} \alpha_i x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} x_i x_j\right)^{\frac{1}{2}}$	$\rho = \lambda = 1$