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Where are Germany's gains from Kyoto? Estimating the effects of global warming on agriculture

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Abstract Motivated by the high abatement costs of the Kyoto Protocol for Germany, this paper is estimating the economic impact of global warming on agriculture in that country. The hedonic approach is used as theoretical background. Stating that land prices are – among others – determined by climatic factors, this approach can consequently be used to value global warming. To avoid a priori restrictions stemming from functional forms, the land price function is modeled as quadratic Box–Cox function that nests a wide range of specifications. In a second step, the estimated results are used to forecast the impact of climate change. The results indicate that German farmers will be winners of climate change in the short run, with maximum gains occurring at a temperature increase of +0.6°C against current levels. In the long run, there may be losses from global warming. However, the net present value from climate change is under the most probable scenarios positive.

1 Introduction

With the surprising ratification of the Kyoto Protocol by Russia and its entry into force on February 16, 2005, the world has made an important attempt to deal with the greenhouse gases. A good opportunity to remember the basic rule of efficient environmental policy: Marginal abatement costs must be balanced against marginal damage costs. This postulation does not only hold for regional environmental problems, but also for global environmental challenges like the increase of greenhouse gases in the atmosphere. Although on a global scale the costs of halting emission growth are probably covered by the immense risks from global climate change, we have to accept that even the best policy could not benefit every single region or country. The expected regional impacts are too heterogeneous. They are expected to range from heavy damages due to sea level rise or more frequent weather extremes to significant benefits due to increased precipitation or lower heating energy demand (for an overview see IPCC 2001). However, an efficient

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policy design would open the option for Pareto-improvements by international distribution processes, making the world as a whole better off.

Many observers doubt that the Kyoto Protocol is an efficient instrument. Actually, there is the acute danger of making little progress in slowing global warming because of the non-inclusion of the U.S. and of countries like India and China with their fast increasing emissions, while incurring substantial costs due to inefficient quantity-type measures (McKibbin and Wilcoxen 2002; Nordhaus and Boyer 2000; Nordhaus 2001). A further problem is the questionable distribution of the reduction goals. Although the marginal costs of energy savings are as higher as higher the level of energy productivity, the efforts to reduce greenhouse gas emissions are concentrated on a few high productivity regions. In Europe, for example, Germany alone will be responsible for approximately 80% of the total EU-15 reductions from Kyoto (Ringius 1999).

The costs for Germany – the third-largest economy worldwide – are immense. Actually, without emissions trading, the Kyoto protocol is estimated to decrease the German GDP in 2010 by about 1.2% against the baseline (Viguier et al. 2003). The authors also forecast a significant heterogeneity in GDP losses across the EU. With emission trading, international differences in the carbon price and therefore abatement costs should internationally level off. McKibbin and Wilcoxen (2003), who allow for emission trading and carbon sink allowances, are more optimistic and forecast the GDP loss in Europe in a range from 0.8% to 1.1% by 2015. However, it should be kept in mind that all figures measure the GDP loss per year, adding up to astonishing values when calculating the net present value over many periods.

Naturally the question arises whether today's national costs incurred by implementing the Kyoto Protocol are made up for corresponding benefits in the future. This paper attempts to find an answer on this question by estimating the impacts of climate change for the German agricultural sector, which is the largest EU-producer of milk (24% share) and pork (22% share), and the second largest producer of grain (22%), sugar (24%) and beef (19%). What is even more important than these figures is the fact that agricultural production is very climate-sensitive. Agriculture is therefore an important candidate for being a potential beneficiary from active climate policy. According to Cline (1992), the expected damages for the U.S. agriculture overtake those from the energy sector by more than 50%, and those from sea level rise by 150%. Similar is the conclusion of Pearce et al. (1996) from their exhaustive literature analysis: They estimate that globally about one fifth of all damages will occur in agriculture.

In contrast especially to the U.S. (see, e.g., the reviews by Adams et al. 1990, 1998, 2001; Lewandrowski and Schimmelpfennig 1999; Mendelsohn and Reinsborough 2007), the literature on agricultural impact estimations is scarce 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; Lang 2001 for Germany). Considering the high shares of Germany's agricultural output within the EU and the differentiated climatic conditions in this country, 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. Rosenzweig and Parry 1994; Wolf 2002), economic production analysis (e.g. Kaylen et al. 1992), and hedonic models (e.g. Chen and McCarl 2001; Dixon and Segerson 1999; Maddison 2000; Mendelsohn and Reinsborough 2007). This study follows the hedonic approach which has been made popular by Mendelsohn et al. (1994). The hedonic approach attempts to value goods which are not traded on markets but are important for the production and/or price building of market goods. Examples are the effects of working conditions on wages or of traffic noise on home prices. Transferred to the climate change problem, the idea of hedonic prices can be used to determine the value of temperature, precipitation, or other climate characteristics. Although there are no markets for these public goods, there is a surrogate market – the market for agricultural land – which is influenced by climate variables. The reason for this direct link is the impact climate has on agricultural productivity. Observed land prices contain information about the economic value of climate, which can be filtered out by appropriate empirical methods.

An important advantage of the hedonic approach is the implied adaptation of agriculture to regional climate. Actually, the maximum land price a farmer is willing to pay should depend on the returns he expects from the farming land under consideration. He will use all his experience and knowledge about the regional climate and other specifics to decide whether – for example – corn, wheat, barley or potatoes are produced. This decision determines the bid for the land, because different crops have different yields, market prices and production costs. Consequently, the observed land prices reflect the maximum value of the land dependent upon the climatic framework and other characteristics. In contrast, when using other approaches, the researcher has to describe this adaptation process explicitly. A growth simulator for wheat, for example, may accurately forecast the wheat output under different climate conditions, but the selection of the land, which is used to produce wheat, has to be determined by an additional model.

In the following, the theory of hedonic prices and the estimation process is described in “Section 2”. “Section 3” gives an overview to the data used for the estimation. The empirical results are provided in “Section 4”. Finally, “Section 5” rounds up by a short summary.

2 Theory of hedonic prices

The hedonic approach is used to explain prices and price differences of heterogeneous inputs, intermediate goods or outputs. In this study, the focus is on agricultural land and therefore an input. Productivity differences are a consequence of this heterogeneity, implying non-uniform prices for agricultural land. Actually, the price variation is significant: In Germany, for example, the rental price for one hectare of farm land ranges from 25 € to more than 2,000 €. Following Palmquist (1991), the land price 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, or the local micro-climate described by temperature and precipitation. To derive the willingness to pay for any change in z, land is explicitly separated from the profit function π of the farmer:

$$\left.\begin{array}{c} \max \pi = \sum_{i=1}^{m} p_i y_i - r(z)L \\ s.t.\, F(y,z) = 0 \end{array}\right\} \pi^* = \sum_{i=1}^{m} p_i y_i^*(p,z) - r(z)L \tag{2}$$

In Eq. 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 non-land inputs respectively outputs, with the inputs being the whole bundle of variable inputs save for farmland. When inputs and outputs are grouped together into one vector *y*, often the term "netputs" is used, with outputs being identified by a positive and inputs by a negative sign of the vector elements. Technological restrictions are implemented by the transformation function *F*(*y*,*z*). The transformation function describes the maximum output which can be produced given a certain input bundle and land characteristics *z* (Chambers 1988 260f).[1] *F*(*y*,*z*) can be applied to an one-output world as well as to a multi-output world, with *y* being endogenous, whereas *z* – an important determinant of firm productivity – is exogenous. The prices *p* are also assumed to be exogenous.

This simple model allows for two channels of how climate may influence the behavior of farmers. First, *z* is an element of the transformation function *F*(*y*,*z*). That is, the maximum output from one unit of land is dependent on local climate conditions. And second, land prices and therefore profits are also dependent on the vector *z* (Eq. 1).[2]

From Eq. 2, the maximum willingness to pay for one unit of land θ is given by

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

According to Eq. 3, θ is not only a function of *z*. Actually, to determine the unbiased effects of *z* on land prices, control variables for netput prices and profit levels ($\widetilde{\pi}$) are required. Any direct estimation of the hedonic price function 1 would result in biased results since important determinants of observed land prices are not considered. $\widetilde{\pi}$ is the feasible profit level of the market where the firm is active, sometimes also called the "desired profit level" (Palmquist 1991 p.83). The feasible profit level is zero for competitive markets, i.e. for markets where each supplier is small relative to the market size and where he has to accept market prices as given. To impose linear homogeneity in prices, the dependent variable θ as well as $(m-1)$ netput prices have to be divided by the price of the *m*th netput.

Equation 3 is the basis for estimating the value of a climate change scenario. For example, shadow prices for each single out of the *q* elements of *z* can be determined by differentiating the bid-function with respect to the corresponding element:

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

The shadow price s_k is the willingness to pay for a marginal increase of the *k*th element z_k. Therefore, s_k can also be interpreted as the inverse of the demand function for the specific characteristic z_k (Palmquist 1991).

To determine the monetary impact of a more complex climate change scenario, the land price bids under two climate regimes have to be compared:

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

$s^{z^0 z^1}$ 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

[1] Due to imperfect information or different management skills, not every single farmer will be able to fully exploit the opportunities of the managed land. Among others, the error term in the regression equation captures for these inefficiencies. The estimation results therefore represent an average relation.

[2] Note that land as well as the price of land is excluded from *y* and *p*, respectively.

simultaneously over a part or the whole z-vector. For example, global climate change may have effects on temperature, precipitation, weather extremes, etc. Eq. 5 can then be used to value such scenarios. Of course, neither s_k nor $s^{z^0 z^1}$ are restricted to bear a certain sign, but may be positive ("public good") or negative ("public bad). Going one step further, slight modifications of Eq. 5 allow for the monetary valuation of any simulation scenario. An important example is the simulation of climate change accompanied by a simultaneous increase of world food prices due to this climate change (Darwin et al. 1995).

Although theoretical considerations do not dictate a specific functional form for the bid equation, a highly flexible functional form has the advantage of not restricting the results ex-ante by a specific function. Following Halvorsen and Pollakowski (1981), a quadratic Box–Cox (QBC) that nests a wide range of specifications is used in the empirical part. Suppressing firm, region and time indices and collecting all explaining variables in a vector x, the Box–Cox function can be written as

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

where

$$\theta^{(\rho)} = \begin{cases} \frac{\theta^{\rho}-1}{\rho} & \text{if } \rho \neq 0 \\ \ln \theta & \text{if } \rho = 0 \end{cases}, \qquad x^{(\lambda)} = \begin{cases} \frac{x^{\lambda}-1}{\lambda} & \text{if } \lambda \neq 0 \\ \ln x & \text{if } \lambda = 0 \end{cases} \tag{7}$$

and $n=q+m$.

To be defined for all values of ρ and λ, the base variables θ and x must be strictly positive, which is the case in this study with the exception of some (non-transformed) dummies. In most instances, we can expect to find the estimates of ρ and λ in the range between [−1, 1].

The immense flexibility of the QBC can immediately be recognized from some specific cases of this function, which include – among others – the log-linear, the generalized Leontief and the Translog function. For example, by imposing the restrictions $\rho=\lambda=0$, one receives the Translog functional form. Therefore, by using e.g. likelihood-ratio tests, the QBC is an appropriate instrument for the statistical discrimination among different functional forms. In the empirical part of the paper, some tests on specific forms are presented.

Due to the panel organization of the data set, the base model uses a fixed effects estimator to determine the parameters of Eq. 6. That is, both the dependent (θ) and the independent (x_i) variables are expressed as deviations from their group means, with the groups being defined as the region where a certain farmer is active (41 groups=regions). The group-specific constants are recovered in a second step and are equal to the 41 elements of the α-vector. To test for the robustness of the results, two control models without group-specific constants are also estimated. The α-vector then degenerates to a scalar and can be interpreted as the usual intercept.

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

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

where N is the number of observations, δ is the parameter vector compatible to x (i.e. the vectors β and γ), and ε is the corresponding error term assumed to be normal distributed. To maximize the likelihood function, a grid search over the range $\rho\in[-2, 2]$ and $\lambda\in[-2, 2]$ was programmed, determining the maximum likelihood estimations of δ by least squares based on the $\rho-\lambda$ transformed data.

Finally, it should be noted that the estimation of a fully parameterized QBC with two different transformation variables (λ and ρ) is cumbersome or even impossible. Actually, the QBC is described by $n + n(n+1)/2$ slope parameters and two transformation variables λ and ρ. Consequently, given the 10 variables used in this study and ignoring the constant (s), we would have to determine 67 parameters. Although the dataset of this study has 794 observations and is therefore quite exhaustive, the number of free parameters has to be reduced. Otherwise, the optimization process will either break down or will produce nonsensical estimates. To deal with this problem, the interaction terms γ_{ij} are estimated only for the climate variables warmth and precipitation, but not for the other variables of the regression equation. This reduces the number of slope coefficients to 13 and is in line with the findings of Cropper et al. (1988), who suggest a linear Box–Cox specification (i.e. without interaction terms) in the case of problems with the estimation procedure.

3 The data

The paper is based on two different data sets: First from a representative number of farmers in West Germany (more than 8,000) who record to the Federal Ministry of Agriculture, and – second – on weather data from the German Weather Service. Both datasets are available in panel form over 5 years, covering the period from 1990 to 1994. Unfortunately, the Ministry of Agriculture does not publish individual farm data. However, information for 5 different specializations of the farms, spatially differentiated by 41 regions (see Fig. A-1 in the Appendix for the geographical demarcation) was provided to the author. Therefore, information about a representative farm for each specialization, each region and each year is available. Due to the fact that some kinds of specialization play no role in some regions, and after dropping some outliers[3], the actual number of observations is 794 and therefore somewhat lower than the theoretical maximum of 1,025 observations (41 regions, 5 specializations, 5 years).

Land prices r are measured as yearly hectare rents to be paid. Actually, renting farm land is very common in Germany, and the available rent prices are much more reliable than prices for buying land. To account for differences in land quality aside from climate characteristics, the altitude above sea level, the slope of the land and specialization dummies are used. The slope of the land is measured by the subsidy paid to farmers in "disadvantaged regions" due to the link of this subsidy to the slope of the cultivated land: The higher the slope, the higher subsidy. Furthermore, an input price index and an output price index are determined, with the input price being used to normalize the output price index and the dependent variable. This normalization ensures linear homogeneity in netput prices. The input price index p_L is a cost-share weighted mean over labor, capital and material prices. Following the proposal of the Ministry of Agriculture, the labor price of the mainly self-employed farmers is based on the opportunity costs of the farmers. As for the

[3]Outliers with very high or very low land prices (more than 1,500 €/ha respectively less than 70 €/ha) are ignored.

price of capital, the user-cost of capital concept is used. Parallel to the input side, six different outputs (crops, oilseed, potatoes, fruits and vegetables, milk, meat) are aggregated into one single revenue-share weighted output price index p_O. Profits are calculated as the difference between total revenues and total cost, the latter including land expenses.[4] Table 1 presents detailed information on these variables.

Climate data for each day of the observation period is available from more than 100 weather stations in Western Germany. Since some of the weather stations are not relevant for agricultural production, in a first step all stations on mountain tops and within cities are eliminated. For the remaining 75 stations, the available information is concentrated in two climate variables which are relevant for crop growth: a) Effective temperature sum (ets) during April to September, which is the critical growth and harvest period, and b) precipitation (prec) during the same time period. The idea behind ets is to sum up the daily values of degree Celsius exceeding 5°C, which is the most important threshold for plant activity:

$$\text{ets} = \sum_{t=\text{April},01}^{\text{September},30} \max\left\{\left({}^{\circ}\text{temp}_t - 5\right); 0\right\} \tag{9}$$

In Eq. 9, $^{\circ}\text{temp}_t$ is the daily mean temperature in degree Celsius. Only the period from April to September is considered, because these months are the critical ones for the crop growth cycle in Germany. Similarly, only summer rainfall is considered in the precipitation variable:

$$\text{prec} = \sum_{t=\text{April},\,01}^{\text{September},\,30} \text{prec}_t \tag{10}$$

One problem to deal with is the possible slow adjustment process of land prices to climate changes. Farmers typically first negotiate over land prices and then produce. The maximal price they are willing to pay for land is based on their expectations about the climate conditions, not the actual values which are influenced by random weather events. By assuming that expectations are based on the long-run climate in a certain region, the 5-year mean values of ets and prec are used for the land price estimations.[5]

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 of the relevant stations is used. Figure 1 shows the regional distribution of ets and prec for Germany.

4 Empirical results

The coefficients of the hedonic function 6 are estimated by a two-dimensional grid search over the likelihood function 8. The program code is written in GAUSS. To test for the robustness of the results, four versions of the model are estimated: A base model which allows for region-specific fixed effects, and three control models. Control model I is

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

[5]When working with yearly weather data, it seems more plausible to explain farm profit and not land prices (for an application see Deschenes and Greenstone 2004)

Table 1 Descriptive statistics of the data set

	Description	Mean	Median	SD	Min	Max
Explained variable						
Land price	Gross rent per year €/ha	245.4	215.1	133.3	70.1	1,261.0
Land characteristics						
ets	Effective temperature sum in °C, April to September	1,762.4	1,753.8	155.4	1,427.2	2,173.0
prec	Precipitation in mm, April to September	418.4	392.0	103.6	211.5	923.4
altitude	Altitude (meters above sea level)	254.0	231.0	185.9	7	740
slope	Public subsidy for disadvantaged land (€ per ha)	24.7	15.9	25.7	0.0	147.1
Economic environment and profits						
p_{I}	Cost-share weighted index for inputs other than land	101.2	100.4	8.1	78.2	153.9
p_{O}	Revenue-share weighted index for outputs	94.9	93.4	10.0	64.8	140.4
Profit	Revenues minus total cost, €/ha	153.7	0.1	363.5	0.0	4,252.4
Specialization dummies						
S_0	Equals 1 if specialized on market crops, 0 otherwise	0.229	0.0	0.421	0	1
S_1	Equals 1 if specialized on feed production, 0 otherwise	0.257	0.0	0.437	0	1
S_2	Equals 1 if specialized on animal production, 0 otherwise	0.218	0.0	0.413	0	1
S_3	Equals 1 if specialized on a) multi-year plants like fruits or wine or b) vegetables, 0 otherwise	0.086	0.0	0.280	0	1
S_4	Equals 1 for farms without specialization, 0 otherwise	0.210	0.0	0.408	0	1

Number of observations: 794. Land rent, prices and profits in 1990-values. Mean input and output price indices equal 100 in 1990.

eliminating region-specific constants and instead assumes one common constant, control model II is compressing the panel structure to a cross-sectional data set by averaging over the 5 years, and – finally – control model III is estimating a linear panel model (i.e. $\rho=\lambda=1$).

As can be seen from Table A1 in the Appendix, most parameters are significant and all significant parameters have the expected sign. For example, temperature has a positive effect on land prices, whereas its squared term is negative. That is, the relationship between land prices and warmth follows an inverted U-shaped curve – an obviously senseful result. With respect to the non-climatic variables, especially the normalized output price, the slope of the land and a specialization on multi-year plants like wine or fruits are important factors affecting the land price. In the rare cases a parameter takes the wrong sign, e.g. the positive sign of the altitude in one of the model, the corresponding parameter is insignificant. Due to the good fit and if not indicated otherwise, in the following the results of the base model are described.

To begin with a statistical analysis of the results, likelihood-ratio tests were run to check for the relevance of the economic model and for simplified functional forms. Test values are calculated by re-estimating function 6 with additional restrictions. The results, as 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 Generalized Leontief, the linear or the log-linear form (not shown) are significantly rejected. Similarly, the impact of climate conditions on land prices is confirmed for a convincing significance level.

Figure 2 is illustrating the impact of the climate variables on agricultural land. The left-hand side of the figure shows the predicted differentials of regional land prices from the Germany-wide mean. As can be seen, high prices are predicted especially for some mid-

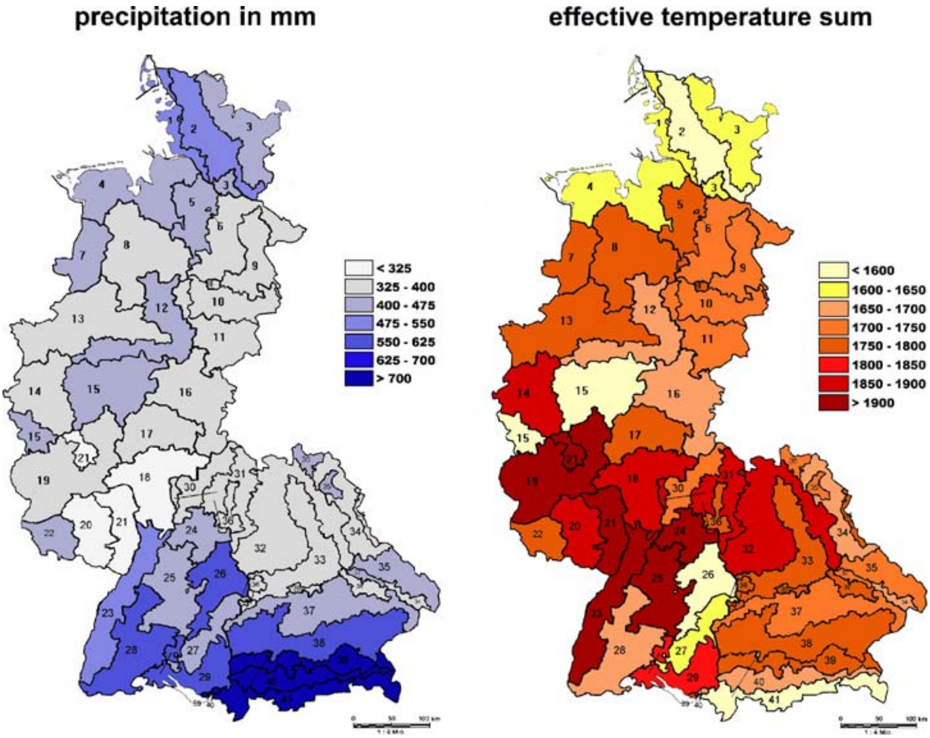


Fig. 1 Precipitation and effective temperature sum by regions. The figures show the mean values over the periods 1990 to 1994

Table 2 Likelihood-ratio-tests on simplified model structures

Hypothesis	Restrictions	Degrees of freedom	$\chi^2_{0.95}$	λ_{LR}	Conclusion
All slope parameters are zero	$\beta_i = 0$ $\gamma_{ij} = 0 \quad \forall i, j$	13	22.4	1,088.8	Reject
Climate conditions are irrelevant	$\beta_i = 0$ $\gamma_{ij} = 0 \quad i, j = \text{ets, prec}$	5	11.1	44.0	Reject
Temperature doesn't matter	$\beta_i = 0$ $\gamma_{ii} = \gamma_{ij} = 0 \quad i = \text{ets}, \quad j = \text{prec}$	3	7.8	18.3	Reject
Moisture doesn't matter	$\beta_i = 0$ $\gamma_{ii} = \gamma_{ij} = 0 \quad i = \text{prec}, \quad j = \text{ets}$	3	7.8	33.9	Reject
Specialization dummies don't matter	$\beta_{S1} = \beta_{S2} = \beta_{S3} = \beta_{S4} = 0$	4	9.5	162.6	Reject
Translog specification is adequate	$\rho = \lambda = 0$	2	6.0	35.4	Reject
Generalized Leontief is adequate	$\rho = 1$ $\lambda = 0.5$	2	6.0	718.6	Reject
Linear Box–Cox is adequate (i.e. without interaction terms)	$\gamma_{ij} = 0 \quad i, j = \text{ets, prec}$	3	7.8	28.3	Reject

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

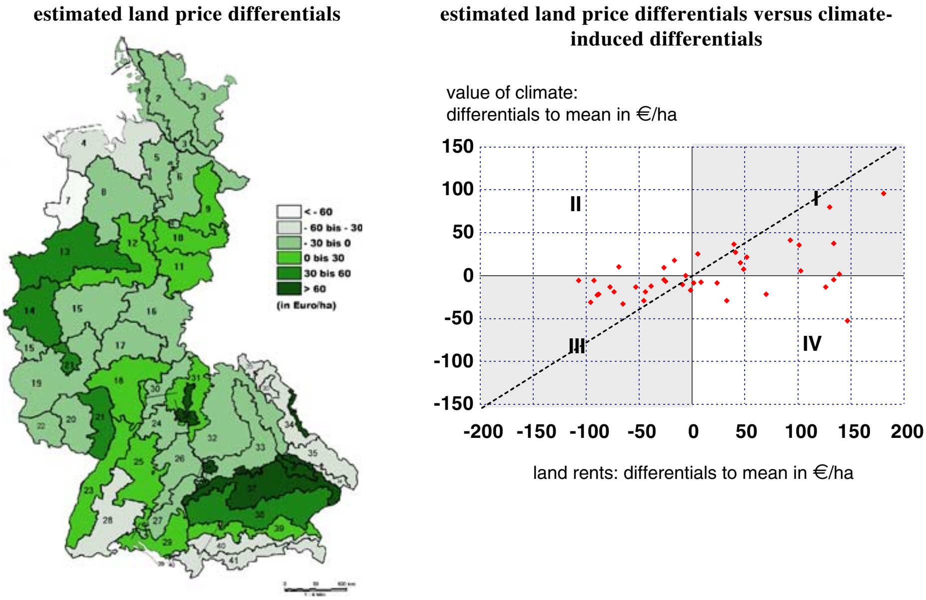


Fig. 2 Impact of current climate on land prices. The *left-hand side figure* shows estimated deviations of regional land prices from the Germany-wide mean. The *right-hand side figure* plots these estimated land rent differentials against the isolated climate-induced differentials. All results based on parameters from the base model

western and southern parts of Germany. On the right-hand side, the contribution of climatic differentials to these land price differentials are plotted. The latter results are calculated by setting all explaining variables except ets and prec at sample mean values. The diagram clearly shows a concentration of the plot points in the first and the third quadrant, indicating that land prices and climate conditions are positively related. That is, low-price land is more probable in regions with relative unfavorable climatic conditions and vice versa. Climate conditions are therefore a main determinant of total land prices and are only in rare cases overcompensated by other variables (quadrants II and IV). Second, the diagram also shows that the majority of the plot points is above the diagonal in quadrant III, but below the diagonal in quadrant I. This indicates that in regions with favorable climatic conditions a further positive effect of the other variables on land prices occurs (quadrant I). Similarly, land prices in regions with less attractive climatic profiles are further depressed by the non-climatic variables (quadrant III).

Based on Eq. 4, the shadow prices of the temperature variable are plotted in Fig. 3 (*right-hand side*). As intuitively expected, there is a negative, non-linear relationship between the level of ets and the shadow price of ets. More interesting is the turning point from positive to negative values of the shadow price: This turning point is estimated at about 1850 heating degree days (ets) and therefore significantly beyond the current mean. The economic interpretation of this result is obvious: As for a representative German farmer, the current temperatures are a little bit too low. That is, farmers in this country would be willing to pay for a slight temperature increase.

How robust is this main result? To get an idea of the sensitivity to alternative model setups, the shadow price of warming is also calculated for the control models I (no fixed effects), II (one-period-model) and III (linear specification). Figure 4 compares the estimates.

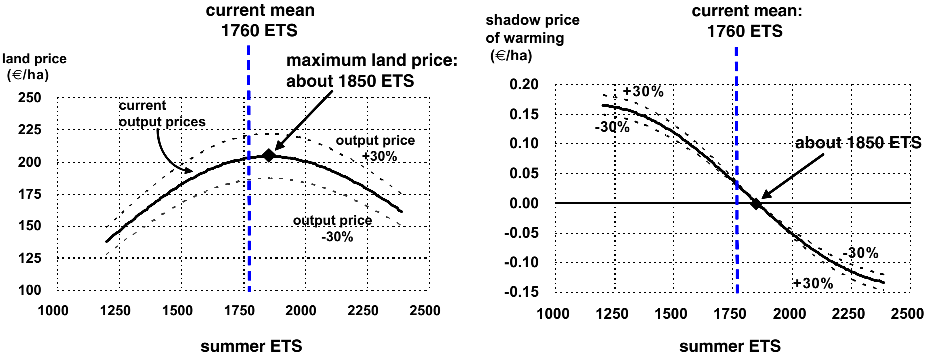
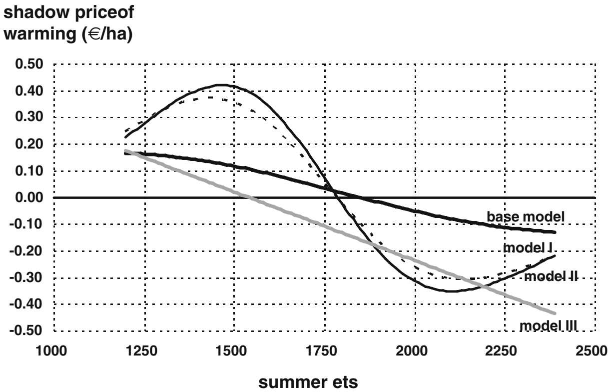


Fig. 3 The relationship between absolute land prices and temperature (*left-hand side*) and the shadow price of warming and temperature (*right-hand side*), estimated for different output price levels. The shadow price indicates the change in the willingness to pay for one ha of land given an increase of ets by one unit. Calculations are based on the base model applied to a representative farmer

When we substitute the full parameterized base model by the control models, the role of temperature for land values is increasing. This increasing sensitivity to temperature is in line with expectations, because larger models tend to reduce the impact of the single variables relative to their impact in a sub-model. What is more important, however, is the stability of the general picture: The shadow price of warming is positive in relatively cold regions and gets lower in warmer areas. Finally, the shadow price turns negative, i.e. temperatures are beyond the optimum for agricultural purposes. All estimation results, save from control model III, confirm that this turning point is anywhere between 1,800 and 1,900 ets-points.

Global warming will not be limited to a marginal change of temperature or precipitation, however. Although the projections have been revised downwards against former estimations by the IPCC (2001), the expected minimum warming is 1.4°C in this century, determined as the average surface warming of our planet. This forecast corresponds to about 0.15°C per decade. Because Germany is expected to be close to the global average (IPCC 2001), the following simulation assumes three different warming scenarios around this forecast: A warming per decade of 0.1°C, 0.2°C and 0.3°C, respectively. Because only small changes are expected for precipitation in Germany, all precipitation levels are left unchanged from the current values. For all scenarios, the regional effects on land prices are

Fig. 4 Shadow price of warming with different model setups



estimated and then aggregated to a Germany-wide figure. The weights for the aggregation are the hectare-size of a particular region.

The results indicate that the German agricultural sector will be among the winners of global warming – at least in short run. Following these results, maximum benefits will be realized with a temperature increase of 0.6°C against the current levels. Economically, the gain will be about 1% of the current land values (Fig. 5, left-hand side). Therefore, on the aggregate level, the agricultural sector has the potential to increase land productivity and increase outputs, all else being equal. Only in the long run, if summer temperatures should increase by more than 1.0°C, benefits will melt and finally become negative. Due to the concave shape of the benefit curve, losses will increase quickly with further warming.

On the right-hand side of Fig. 5, the net present values over all future periods and of the three different warming scenarios are plotted against the relevant discount rate. As can be seen, a slow growth of summer temperatures (+0.1°C per decade) would result in positive net present values regardless of the discount rate. A faster temperature increase will shift the damages closer to the present and consequently shorten the available time interval with benefits. But even with a 0.2°C warming per decade, the net present values are all positive. Only the catastrophic scenario with an assumed 0.3°C warming per decade is producing negative net present values for low discount rates. As for this scenario, a discount rate of 5% is necessary to return to positive net present values.

These surprisingly optimistic results may further improve by – so far not considered – macroeconomic impacts from global warming. As Reilly and Hohmann (1993) state, an inelastic world demand curve for food is meeting a climate-sensitive world supply curve, which is negatively affected from global warming. 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, higher world market prices will multiply these gains. In the long run, when climate change is estimated to be negative for agricultural productivity in Germany, even a small price increase may easily offset the decline in productivity, however. Figure 6 illustrates this effect. The graph shows the net present value of a 0.2°C warming scenario (per decade) combined with a 0.5% respectively a 1.0% output price growth scenario (price growth per year). Obviously, both the price increases and the short-term productivity gains contribute to a dramatically improving net present value from climate change.

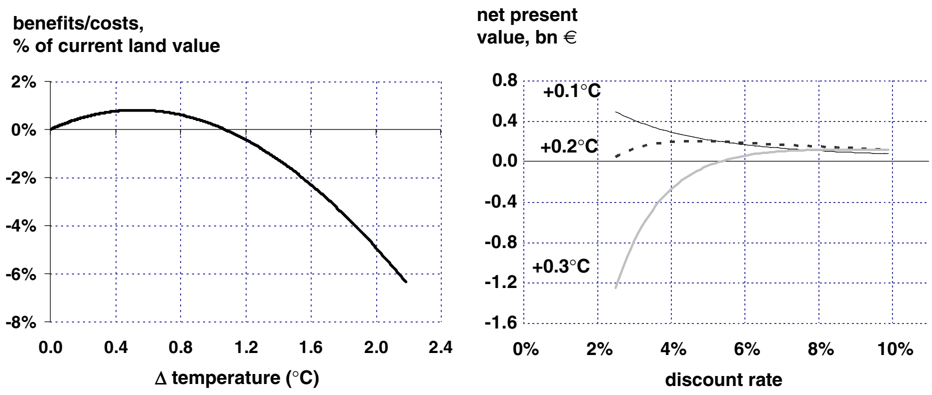


Fig. 5 Net present values of different global warming scenarios for agriculture in Germany. Global warming scenarios as temperature increase per decade. Calculation based on constant netput prices. Net present values in prices of 1990

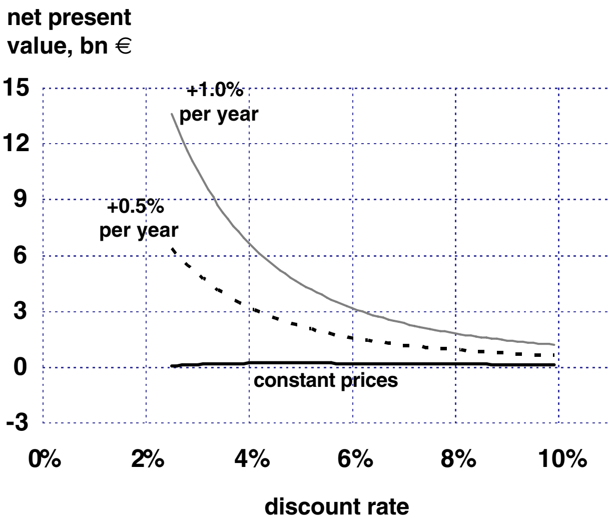


Fig. 6 Net present value of global warming with different output prices. The underlying warming scenario is +0.2° per decade. Constant output prices are compared to a scenario with 0.5% growth per year respectively 1.0% growth per year. Net present values in prices of 1990

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, the land price changes from one specific warming scenario – +1.0°C against current levels – are broken down to the regional level. Although the aggregate impact is near to zero (left-hand side of Fig. 5), the estimations show that more than 50% of the agricultural area in Germany will be positively affected. The largest winner are in the northern and the middle part of Germany, where also the current land prices are relatively high. Somewhat surprisingly, the areas in the very south (near the Alps) with their relatively unfavourable climatic environment are not amongst the winner of climate change (Fig. 7).

5 Summary

This study attempted to evaluate the impact of climate change on agriculture in Germany, using the hedonic approach. The main advantage of this technique is the consideration of the full range of adaptation options to the climatic environment. A Box–Cox form was employed to allow for very flexible relationships between land prices, temperature, precipitation, and a supplementing set of explaining variables like the slope of the land, altitude, or output prices. The empirical results indicate that the willingness to pay for land is significantly influenced by the climatic environment. Combining the estimation results with a global warming scenario, the German agricultural sector is estimated to gain from a temperature increase. Maximum gains are estimated with a temperature increase of +0.6°C against the current levels. Should the temperature increase surpass +1.0°C, however, the impact on the farming sector is clearly negative.

The net present values of climate change depends on the speed of climate change and on the discount rates. Given a moderate warming scenario of 0.2°C per decade or below and discount rates of 5% or more, it is hard to find any negative impact of climate change on the German agricultural sector. Should the world prices for agricultural products increase as a consequence of global climate change, the impact on farming would even be strongly positive. Notwithstanding this general optimistic picture, some regions could be quite

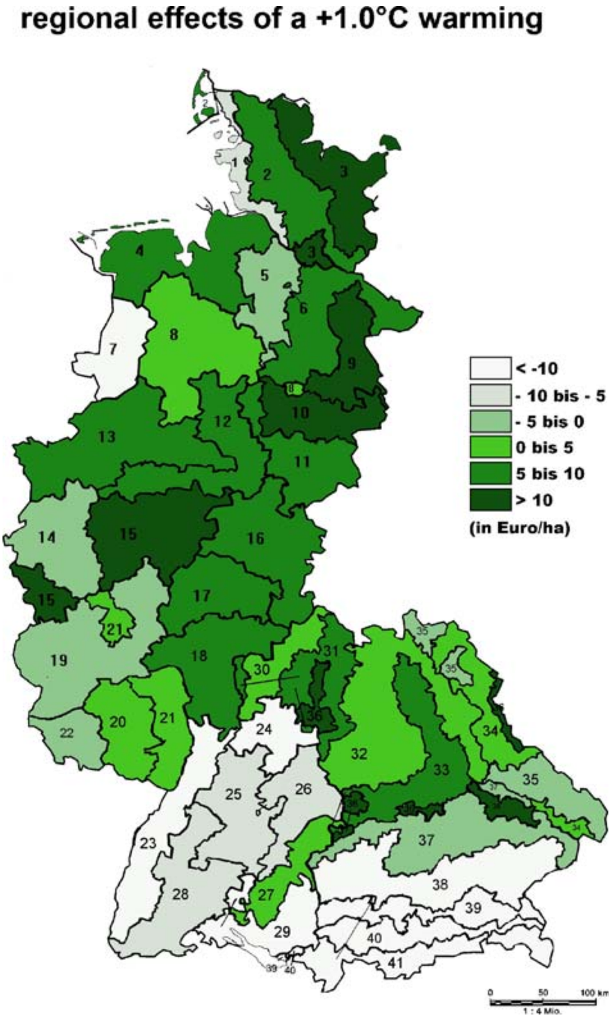


Fig. 7 Regional distribution of profit and losses from global warming. Changes in the willingness to pay for 1 ha of land, estimated from the base model

negatively affected, however. Interestingly, a very similar conclusion for the US was drawn by Lewandrowski and Schimmelpfennig (1999). Especially farmers in the southern part of Germany may find themselves among the losers of global warming.

Although the effects of climate change are obviously not limited to agriculture, this industry is among the most affected sectors. As for Germany, the results of this study show that a moderate warming will increase, not decrease the productivity of this sector. Formulated the other way round, a global cooling of the atmosphere as expected just three decades ago (Matthews 1975) would harm the agricultural sector in Germany – and perhaps the country as a whole – much stronger. Summing up, the costs of the Kyoto Protocol relying on inefficient quantity-based measures will be significant, especially for Germany which shares the largest burden within the EU. Because no mechanism does exist which distributes from the winners of Kyoto to those countries who bear the burden, the question for the benefits of Kyoto is still an open one for Germany. At any rate, the agricultural sector seems not to benefit from the national efforts.

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Appendix

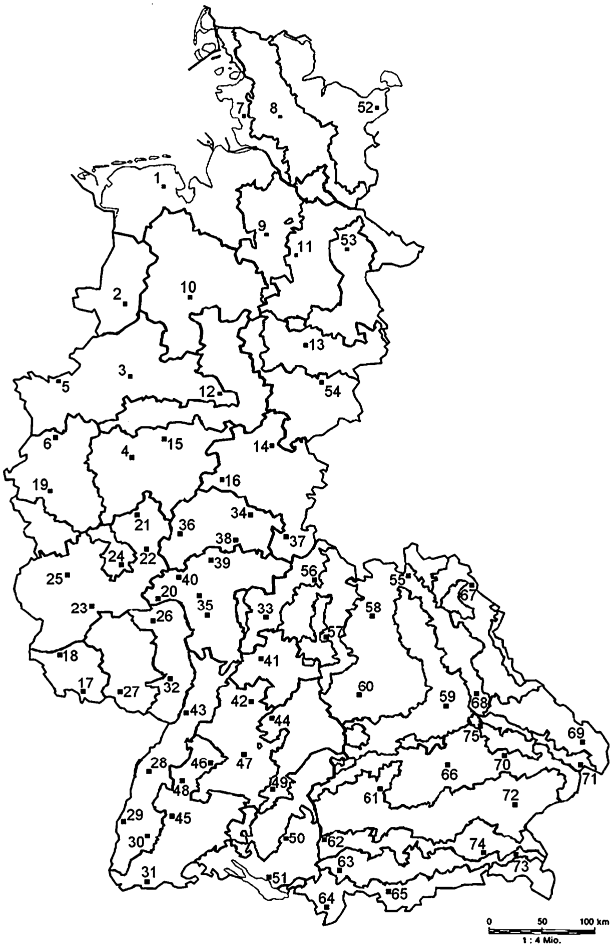

Fig. A-1 Regional distribution of production areas and weather stations

Table A1 Estimation results

Explained variable: price of agricultural land $\theta^{(\rho)}$

	Base model (QBC with fixed effects)	Control model I (QBC, without fixed effects)	Control model II (QBC, one period model)	Control model III (linear model, fixed effects)
Const		−33.74291*** (−7.58)	−36.54265*** (−4.03)	
ets$^{(\lambda)}$	0.04166*** (2.72)	2.52170*** (8.85)	2.51978*** (4.49)	14.11925*** (2.73)

Table A1 (continued)

Explained variable: price of agricultural land $\theta^{(\rho)}$

	Base model (QBC with fixed effects)	Control model I (QBC, without fixed effects)	Control model II (QBC, one period model)	Control model III (linear model, fixed effects)
$\text{prec}^{(\lambda)}$	0.00450	0.30938***	0.37207***	1.15722
	(1.54)	(4.84)	(3.14)	(1.52)
$\text{ets}^{(\lambda)} \times \text{ets}^{(\lambda)}$	−0.00018**	−0.04332***	−0.04056***	−0.02541**
	(−1.99)	(−9.04)	(−4.45)	(−2.00)
$\text{ets}^{(\lambda)} \times \text{prec}^{(\lambda)}$	−0.00005***	−0.00486***	−0.00542***	−0.00758***
	(−3.66)	(−5.39)	(−3.21)	(−3.63)
$\text{prec}^{(\lambda)} \times \text{prec}^{(\lambda)}$	0.00001	−0.00073**	−0.00101**	0.00119
	(1.29)	(−2.44)	(−2.01)	(1.33)
$\text{altitude}^{(\lambda)}$	0.00007	−0.00272***	−0.00189	−0.08163
	(0.81)	(−4.15)	(−1.32)	(−0.78)
$\text{slope}^{(\lambda)}$	−0.00250***	−0.02260***	−0.03138***	−1.63008***
	(−8.21)	(−15.16)	(−7.66)	(−8.21)
$\text{profit}^{(\lambda)}$	0.00080***	0.00151***	0.00365***	0.07381***
	(4.96)	(5.58)	(4.22)	(4.77)
$p_{\text{O}}^{(\lambda)}$	0.00178***	0.02584***	0.05697**	0.18420***
	(3.67)	(4.42)	(2.16)	(3.63)
S_1	0.01136	0.05420**	0.10129**	25.21806
	(1.42)	(2.54)	(2.10)	(1.43)
S_2	0.02784***	0.06023***	0.01232	27.86026***
	(4.26)	(2.70)	(0.19)	(4.25)
S_3	0.12379***	0.34067***	0.42615***	191.84059***
	(16.18)	(12.98)	(5.99)	(16.15)
S_4	0.01247	0.02462	0.00879	14.36889
	(1.61)	(1.12)	(0.16)	(1.62)
λ	0.79	0.50	0.51	1.00
ρ	−0.28	−0.12	−0.08	1.00
LnL	−4265.6	−4529.4	−917.1	−4621.5
Observations	794	794	165	794
df	740	780	151	740

Asymptotic t-statistics in parentheses. ***, ** and * denote a significance level of 1%, 5% and 10%, respectively (two-sided). The explained variable as well as the output price is normalized by the input price. The base model as well as control model III allow for 41 region-specific constants.

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