Do Different Measurements of Soil Quality Influence the Results of a Ricardian Analysis? – A Case Study on the Effects of Climate Change on German Agriculture

Beeinflussen verschiedene Bodenqualitätsmaße die Schätzergebnisse einer Ricardischen Analyse? Eine Fallstudie zu den Auswirkungen des Klimawandels auf die deutsche Landwirtschaft

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Abstract

This study assesses the potential impact of future climate change on agricultural land rents in Germany using a Ricardian approach. In addition to including common explanatory variables, we focus on the effects of different indicators of soil characteristics when explaining land rental prices. The analysis is based on data from the official farm census 1999, weather data from the German National Meteorological Service and different soil data-bases at the county level. Different classifications of soil quality do not influence the results of our Ricardian analysis. The results of spatial error models indicate higher land rental prices for locations with more productive soils and higher mean annual temperatures. Also a lower land slope, a smaller share of rented land and (in some cases) less spring precipitation increase land rental prices. To estimate the effects of changing climatic conditions on future land rents, we draw on data from the regional climate model REMO for 2011-2040. Our models show an average land rent increase of 10-17% resulting from the expected changes in temperature and spring precipitation. According to our results future climate change will have an overall positive but spatially heterogeneous impact on the agricultural income in Germany.

Key words

climate change; German land rents; Ricardian analysis; spatial econometrics

Zusammenfassung

Mit Hilfe des Ricardischen Ansatzes untersucht diese Studie mögliche Auswirkungen des künftigen Klimawandels auf landwirtschaftliche Bodenrenten in Deutschland. Bei der Erklärung von Landpachtpreisen konzentrieren wir uns neben gängigen unabhängigen Variablen auf die Effekte verschiedener Indikatoren der Bodenqualität. Die Untersuchung basiert auf Daten der Landwirtschaftszählung 1999, Wetterdaten des Deutschen Wetterdienstes und unterschiedlichen Quellen zu Bodendaten auf Landkreisebene. Die Art des verwendeten Bodenqualitätsmaßes beeinflusst die Ergebnisse unserer Ricardischen Analyse nicht. Der Ergebnisse räumlicher Fehlermodelle deuten auf höhere Landpachtpreise in Gebieten mit sehr produktiven Böden und hoher Jahresdurchschnittstemperatur hin. Eine geringere Hangneigung, ein geringerer Anteil an gepachtetem Land und (in einigen Fällen) geringere Frühjahrsniederschläge führen ebenfalls zu höheren Landpachtpreisen. Um die Auswirkungen sich verändernder klimatischer Bedingungen auf künftige Bodenrenten abzuschätzen, nutzen wir Daten des regionalen Klimamodells REMO für den Zeitraum von 2011-2040. Unsere Modelle zeigen, dass die vorhergesagten Temperatur- und Niederschlagswerte einen durchschnittlichen Anstieg der Bodenrenten um etwa 10-17 % bedeuten würden. Entsprechend unserer Ergebnisse wird ein künftiger Klimawandel voraussichtlich einen insgesamt positiven aber räumlich heterogenen Einfluss auf das landwirtschaftliche Einkommen in Deutschland haben.

Schlüsselwörter

Klimawandel; deutsche Bodenrenten; Ricardische Analyse; räumliche Ökonometrie

1 Introduction

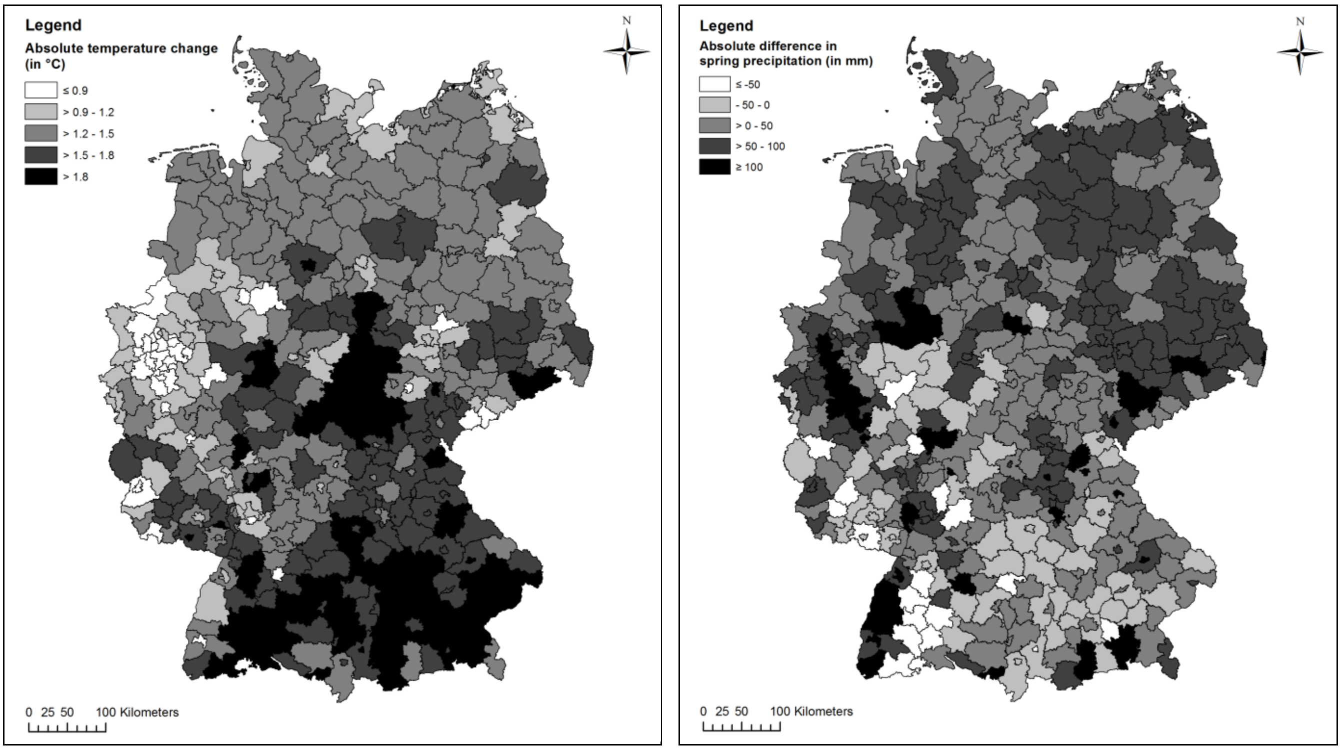
The increasing concentration of greenhouse gases in the atmosphere due to natural and anthropogenic causes will change the climate around the world. This climate change will especially impact climate-sensitive systems, such as agriculture, and thus affect the productivity and the profitability of agricultural production. The IPCC (Intergovernmental Panel on Climate Change) expects an increase in the mean temperature of Europe of 2.1°C to 5.3°C by the end of the 21st century and an increase in precipitation in northern Europe (IPCC, 2007a). As shown in Figure 1, the predicted changes in the mean annual temperature and the spring precipitation are distributed unevenly within Germany, the country analysed in this study.

Because the projected climate change will not be evenly distributed in space, the agronomic and economic impacts of the projected change will vary across regions depending on the existing climatic, agronomic and political conditions (HENSELER et al., 2009). For example, SUPIT et al. (2010) found that changing climatic conditions, such as temperature and radiation, increased the yield potential of several crops in the UK and some regions in northern Europe over the time period 1976-2005, but potential crop yields in southern central Europe decreased. To assess the potential impact of future climate change on the value of agricultural land in Germany, we use a Ricardian approach (MENDELSOHN et al., 1994).

The Ricardian approach is a cross-sectional approach named after the English economist David Ricardo (1772-1823), who stated that the net productivity of farmland is reflected by land rents (MENDELSOHN and REINSBOROUGH, 2007). Corresponding to the hedonic pricing of environmental attributes, the Ricardian approach is used to explain the impact of climate and other variables on the value of agricultural land (cf. MENDELSOHN et al., 1994; MENDELSOHN and REINSBOROUGH, 2007; POLSKY, 2004; for applications for Germany: LANG, 2007; LIPPERT et al., 2009). In response to changing climatic conditions, farmers can adapt their agricultural activities by cultivating different crops or changing livestock species (SEO and MENDELSOHN, 2008; SEO et al., 2010). Thus, '[...] spatial variations in climate result in varying land uses and consequently land values' (POLSKY and EASTERLING, 2001: 135). PASSEL et al. (2012) analyse the impact of climate change on European agriculture and predict sizeable losses for Southern Europe. SALVO et al. (2013) support this finding for Italy. In contrast, climate change will have mixed effects on agriculture in the northern European countries such as Germany (PASSEL et al., 2012).

In Germany, land rental prices are distributed unevenly in space (see also Figure 2a). High rental prices for agricultural land can be found in the north-western and the south-eastern parts of Germany, whereas regions in eastern Germany are characterised by low land rental prices (cf. DOLL, 2001; MAGRARIAN, 2008). In addition to common factors that determine

Figure 1. Predicted changes in mean annual temperature and spring precipitation 2011-2040 (IPCC scenario A1B) compared to mean annual temperature and spring precipitation 1961-1990*



* For detailed information on underlying data and data processing see section 4.
Source: authors' own presentation based on BKG (2010), DWD (2007), MPI ON BEHALF OF THE UMWELTBUNDESAMT (2006)

agricultural production, such as climate and soil, several other factors influence farmland rental prices. FEICHTINGER and SALHOFER (2011) defined two major groups of influencing factors: internal (agricultural) variables and external variables. In addition to the common agricultural production factors, FEICHTINGER and SALHOFER (2011) refer to governmental payments, such as the direct payments from the Common Agricultural Policy (CAP), as internal variables that affect the rental prices of farmland. As external influencing factors, they consider variables describing the market (e.g., farm density), macroeconomic factors and urban pressure indicators (e.g., population density) (cf. FEICHTINGER and SALHOFER, 2011). Furthermore, a high density of livestock increases land rental prices in Germany (BREUSTEDT and HABERMANN, 2011; HABERMANN and ERNST, 2010). Nowadays, nearby biogas plants also have a positive influence on land rental prices (HABERMANN, 2009; PLUMEYER and EMMANN, 2010).

Two studies use a Ricardian approach to analyse land rents in Germany. LANG (2007) estimated the economic impact of global warming on agriculture with a panel data set for the time period 1990-1994 that includes weather data and information on farmers in western Germany. He found that '[...] German farmers will be winners of climatic change in the short run, with maximum gains occurring at a temperature increase of +0.6°C against current levels' (LANG, 2007: 423). He predicted a negative impact on the agricultural sector in the event of a future temperature increase greater than 1°C. LIPPERT et al. (2009) implemented a spatial error model to assess the economic impact of climate change on German agriculture. They draw on 1999 data from the agricultural farm census and German weather data and found increasing land rental prices in regions with a rising mean temperature and declining spring precipitation (the latter except for eastern Germany). The results of simulations under three IPCC scenarios suggest that the land rental prices will increase, so German agriculture will benefit from climate change. However, the extent of such benefits is distributed unevenly in space.

LANG (2007) and LIPPERT et al. (2009) both indicate a positive impact of climate change on German agriculture but neglect important production factors, such as the quality of the soil. We intend to advance these previous Ricardian approaches. In addition to the explanatory variables used previously, we compare the effects of different classification systems of soil quality on the land rental prices and consider a land slope variable. We use the original micro data of the German agricultural census of 1999 provided by the FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000) for our analysis and thus do not need to estimate the missing values for several German counties, as in LIPPERT et al. (2009). Furthermore, we implement additional tests, such as the (robust) Lagrange Multiplier test for spatial autocorrelation in the residuals from the OLS model. We additionally define two different neighbourhood structures to examine the stability of our results. Thus, compared to LANG (2007) and LIPPERT et al. (2009), we account for additional factors of agricultural production, such as the average soil characteristics (including farmland slope), and implement refined econometric methods to deepen the understanding of future climatic impacts on the profitability of agricultural land in Germany.

2 Conceptual Considerations for Model Specification

In this study, we assess the effects of different methods of accounting for soil quality in a Ricardian analysis of German land rental prices. Controlling for soil quality is of particular relevance because the existence of any correlation between an omitted variable and one of the variables explaining land value will lead to biased results. For example, if soil quality is positively correlated with temperature but not considered as explanatory variable, the effect of the former explanatory variables on the land rent will be overestimated. Thus, we include soil quality and land slope as explanatory variables in our analysis.

Several indicators of soil quality are available. We use three approaches to control for soil quality and test the appropriateness of different soil databases for an analysis at a relatively high spatial resolution, such as the county level. One source of global soil information is the Digital Soil Map of the World (DSMW) (cf. FAO, 2003), which is frequently used by scientists all over the world. For example, SEO et al. (2009) used DSMW data for a Ricardian analysis of the distribution of climate change impacts on agriculture across agro-ecological zones in Africa. However, the original low spatial resolution (1:5 million scale) of the DSMW may not be suitable for all analyses, such as those at a more detailed spatial scale. For our analysis, we account for the two most frequent DSMW soil classes at the county level in Germany: dystric cambisols (dummy for less productive soils) and orthic luvisols (dummy for good soil quality). In contrast, a unique regional classification system for the productive capacity of the agricultural land in Germany is available at a relatively high spatial resolution. The quality of farmland was defined all over Germany starting in 1934 to harmonise taxation in the former German empire (*Reichsbodenschätzung*). The resulting soil index (*Bodenzahl*) represents a measure of the productivity of agricultural land. The index ranges from 7 (lowest yield potential) to 100 (best yield potential) and was generated based on the observed grain structure of the soil material, geological development and the state of development of the parent material of the soils. In this context it is important to notice that in contrast to the also available arable index (*Ackerzahl*) the soil index used does not account for different climatic conditions (cf. SCHACHTSCHABEL et al., 1984: 415ff.). As a third data source, we consider the German soil database (*Bodenübersichtskarte*) indicating the parent materials of the soils and select the dummy variable loess, as loess tends to develop into highly productive soils. Additionally, the slope of the farmland plays a role in terms of land cultivation, as a steep land slope can hamper the use of heavy machinery or sometimes exclude the cultivation of certain crops, such as maize.

The basic assumption of the Ricardian approach is that climatic factors, such as temperature or precipitation, influence the rental price of farmland. In Germany, spring precipitation between March and June affects the main growth phase of arable crops and thereby strongly determines the yield and quality of agricultural production. Late precipitation during the harvesting season is less important and is therefore not considered in our analysis.

LIPPERT et al. (2009) implemented a dummy variable east indicating two aspects that differ between eastern and western German: the agricultural structure such as the share of rented land and the natural production conditions such as precipitation (see also Table 1). In eastern Germany the share of rented land is relatively high, so (c.p.) lower land rental prices are expected in eastern regions due to theoretical considerations. On the other hand, the effect of precipitation in eastern Germany is supposed to be positive because of large areas with sandy soils. When using the dummy variable east, these two aspects cannot be interpreted separately.

To separately account for the unequal agricultural structures between the German regions, we consider the share of rented land. The amount of rented land in a region might affect the land rental price. If only a low share of farmland is rented, the shadow prices of the land (marginal land rental prices) can be paid by the tiller, neglecting the fixed costs of the farm. Furthermore, given a low farm density and large farm size, which is often the case in eastern Germany, the demand for rented farmland might be determined by

Table 1. Mean values for variables of interest at the county level

	Year	Germany (N=440)	Western Germany (N=327)	Eastern Germany (N=113)
land rental price (in € / ha UAA[a])	1999	183.02	212.06	98.99
soil index	1981, 1986	46.11	46.96	43.66
land slope (in %)	2008	1.75	1.85	1.48
spring precipitation (in mm)	1961-1990	269.62	287.18	218.83
spring precipitation scenario A1B (in mm)	2011-2040	314.14	326.70	277.80
spring precipitation scenario A2 (in mm)	2011-2040	325.49	341.23	279.95
spring precipitation scenario B1 (in mm)	2011-2040	301.99	314.96	264.45
mean annual temperature (in °C)	1961-1990	8.42	8.51	8.17
mean annual temperature scenario A1B (in °C)	2011-2040	9.86	9.93	9.66
mean annual temperature scenario A2 (in °C)	2011-2040	9.97	10.04	9.73
mean annual temperature scenario B1 (in °C)	2011-2040	9.82	9.90	9.59
share of rented UAA in UAA[a]	1999	0.58	0.47	0.88
share of grassland in UAA[a]	1999	0.32	0.35	0.23

Due to data protection legislation minimum and maximum values of the variables cannot be presented.
[a] UAA = utilised agricultural area
Source: authors' own calculations based on BGR (2007a), DWD (2007), FAO (2003), FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000), FORSCHUNGSZENTRUM JÜLICH (2009), JARVIS et al. (2008), MPI ON BEHALF OF THE UMWELTBUNDESAMT (2006)

only a few farmers. In some regions, this could lead to a nearly monopsonistic situation in the land rental market. The effect of precipitation in relatively dry regions is explicitly considered by means of specific dummy variables (see supplementary analyses in section 5).

Some studies (BREUSTEDT and HABERMANN, 2011; HABERMANN and ERNST, 2010) indicate that a high density of livestock increases German land rental prices. However, animal husbandry may be one opportunity to adapt to future climate change, so we do not include a corresponding proxy variable in our analysis.

3 Econometric Model

An analysis of the spatially heterogeneous impact of climate change on land rental prices may require spatial models (cf. ANSELIN, 1988: 34ff.; LESAGE, 1999: 52f.) to obtain unbiased and efficient estimates. The general version of our model is given by

$$y = \rho Wy + X\beta + u \tag{1}$$

$$u = \lambda Wu + \varepsilon \tag{2}$$

with $\varepsilon \sim \mathrm{N}(0, \sigma^2 \mathrm{I_N})$
and

- y = vector containing the land rental prices in the year 1999 for the 440 German counties (i = 1, …, 440);
- X = matrix containing the observations for m independent climate and non-climate variables at the county level (cf. section 4);
- W = standardised spatial weight matrix;
- I_N = identity matrix;
- u = vector of spatially correlated residuals;
- ε = vector of errors assumed to be normally distributed;
- β = vector containing the regression coefficients for the explanatory variables;
- ρ = spatial lag coefficient reflecting the importance of spatial dependence;
- λ = coefficient reflecting the spatial autocorrelation of the residuals u_i.

The regression coefficients β and, if considered relevant, the spatial lag coefficient ρ and the spatial error coefficient λ are the parameters to be estimated. A significant spatial lag coefficient ρ indicates spatial dependency; a significant spatial error coefficient λ reflects the existence of one or more spatially correlated omitted explanatory variables (i.e., spatial heterogeneity). In principle, there are four possibilities:

(i) $\rho = \lambda = 0$ (common OLS model);
(ii) $\rho \neq 0, \lambda = 0$ (spatial lag model);
(iii) $\rho = 0, \lambda \neq 0$ (spatial error model) and
(iv) $\rho \neq 0, \lambda \neq 0$ (mixed spatial model).

Theoretical considerations indicate that the spatial error coefficient λ may be more important for the regional distribution of land rental prices. Due to data restrictions, it is likely that we do not consider all relevant explanatory variables. If at least one omitted explanatory variable is correlated with different locations in space this will result in spatial autocorrelation of the residuals. In this context, direct payments from the CAP (per hectare subsidies in principal differing between the German federal states) or the distance to markets might matter. The hypothesis that agglomeration effects (captured by a spatial lag coefficient), e.g., due to direct communication between farmers play a role for land rental prices appears to be of less importance. However, we draw on the (robust) Lagrange Multiplier test (ANSELIN et al., 1996) to statistically determine the importance of the two effects.

To examine the stability of the estimation results under different specifications of the relationship of spatial units, two alternative spatial neighbourhood matrices are used: a first order contiguity matrix ($W^{(1)}$) and an inverse distance based matrix ($W^{(idw)}$) (cf. ANSELIN, 1988; LESAGE, 1999). For $W^{(1)}$, all adjoining counties are considered; $W^{(idw)}$ contains the row-standardised inverse distances of each centroid of county $j \neq i$ to the centroid of county i measured in meters. For the analysis we use the programs GeoDa and Stata along with additional routines provided by JEANTY (2010a, b, c, d) and PISATI (n.a.).

4 Data and Variable Construction

The analysis is conducted at the NUTS 3 level (NUTS being the Nomenclature of Territorial Units for Statistics, established by Eurostat). Information on agriculture is obtained from the official German farm census (FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER, 2000). To control for soil quality, different soil data-bases (BGR, 2007a; FAO, 2003; FORSCHUNGSZENTRUM JÜLICH, 2009) are used. The slope of the land is generated based on digital elevation data (JARVIS et al., 2008). We describe climatic conditions by drawing upon weather data from the German National Meteorological Service for the time period 1961-1990 (DWD, 2007) and data from the regional climate model REMO for the time period 2011-2040 (MPI ON BEHALF OF THE UMWELTBUNDESAMT, 2006).

Detailed information on the data and the variables used is given below.

Of all the different agricultural data sources available, the data provided by the official German farm census is the most useful. We base our analysis on the original data from the farm census in 1999 (FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER, 2000). The 1999 data were the most recent available to us; more recent data from 2010 are available in the meantime. Generally, the farm census contains information on all German farms that are above certain thresholds. The farm census from 1999 includes, for example, only farms managing more than 2 hectares of utilised agricultural area (UAA) and a certain number of animals. For the year 1999 information on 471,960 German farms managing more than 17 million hectares is available. As we do not have detailed spatial information on single farms (we only know the county in which each farm is located), we aggregate the data to a lower spatial resolution, the county level. Thus, the analysis is conducted with the mean values for the 440 German counties.

As dependent variable, we use the average (acreage-weighted) *land rental price* per hectare (FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER, 2000) calculated for farms with rental farmland. In 1999, the average land rental price was approximately 183 € per ha UAA. Rental prices tend to be lower for grassland compared to arable land, so we account for the s*hare of grassland* in the total UAA.

The proxy variable *share of rented land* (FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER, 2000) is used as indicator of the demand for and resulting prices of rental farmland. As shown in Table 1, the share of rented farmland differs considerably between western and eastern Germany.

We consider indicators of soil quality and the mean slope of the land within the counties, as these variables are expected to have an influence on land rents. We use three approaches to control for soil quality. The natural soil quality is described by different proxy variables: the *soil index* (kindly provided by FORSCHUNGSZENTRUM JÜLICH, 2009), a dummy variable for the parent materials of the soils given in the German soil database (BGR, 2007a), and two dummy variables derived from the Digital Soil Map of the World (DSMW) (FAO, 2003). Using zonal statistics, the mean value of the soil index is assigned to each county. For the German soil database and the DSMW, the dominant soil class is assigned to each county; only information on agriculturally managed land, as indicated by the German soil database (BGR, 2007b), is considered. From the German soil database, we select the *dummy variable loess*, as loess tends to develop into highly productive soils. From the DSMW, we account for the two most frequent soil classes at the county level in Germany: *dystric cambisols*, representing less productive soils, and *orthic luvisols*, indicating land with good soil quality. Figure A1 (Annex) shows the spatial distribution of soil quality based on the different data sources. All three maps indicate that highly productive soils are located in central and south-eastern Germany; orthic luvisols are additionally found in north-eastern Germany. The variable *land slope* (expressed as a percentage) is generated based on altitudes given by the SRTM (Shuttle Radar Topography Mission) digital elevation data (JARVIS et al., 2008) originally produced by NASA. Again, only information on agricultural land (BGR, 2007b) is considered. The resulting grid is used to calculate zonal statistics and assign corresponding mean values to the counties.

For this analysis, we use weather data from the German National Meteorological Service for the time period 1961-1990 (DWD, 2007). We assume that the weather stations located on mountains are above the agricultural area of the region and, thus, do not reflect the conditions for agriculture; therefore, we neglect all weather stations with an altitude above 1,500 m. As a result, 4,742 stations for precipitation and 663 stations for temperature are used to interpolate the observations spatially. The mean annual *temperature* and average sum of *spring precipitation* (March-June) are generated for all counties using an inverse distance weighted interpolation with the power of one and including the five nearest locations at an output raster cell size of 200 m. The corresponding mean values are then assigned to the county level using zonal statistics. We additionally consider the quadratic terms of the two climate variables in our analysis.

To estimate the potential impact of climate change on future land rents, we draw on IPCC data from the regional climate model REMO (MPI ON BEHALF OF THE UMWELTBUNDESAMT, 2006), which is used for weather forecasting and climate simulation (JACOB, 2001; UBA, 2006). We consider three storylines representing different demographic, social, economic, technological and environmental developments (IPCC, 2007b). The IPCC storyline A1B describes a future world with rapid economic growth, a global population that peaks in the middle of this century and a balanced use of fossil and non-fossil energy resources. The A2 storyline describes a very heterogeneous future world: the global population increases continuously, and economic development is primarily regionally oriented. Per capita economic growth and technological change in this storyline are slower than in other storylines. Storyline B1 describes a convergent future world with the same global population growth as in A1B and a rapid change in economic structures towards a service and information economy with a reduction in material intensity and the introduction of low-emission, resource-efficient technologies. To allow for comparability with previous studies, we replicate the data processing method for the scenario period 2011-2040, as described in LIPPERT et al. (2009). We include all data points below 1,000 m and generate mean values of mean annual *temperature* and sum of *spring precipitation* (March - June) for all counties at a raster cell size of 1,000 m using an inverse distance weighted interpolation with the power of two and including the twelve nearest locations (cf. LIPPERT et al., 2009).

5 Results

In this section, we present the results for the first order neighbourhood matrix $W^{(1)}$; the corresponding main results for the distance based neighbourhood matrix $W^{(idw)}$ are shown in the Annex.

As presented in Table A1 (Annex), our data show high correlations between the grassland share and the following variables: spring precipitation (0.61), mean annual temperature (-0.36) and land rental prices (-0.28). Furthermore, some of the indicators of soil quality are highly correlated with climate variables. Thus, we determine two models considering either spring precipitation (model I) or the share of grassland (model II) as explanatory variables. Additionally, there are three specifications of both models (a, b, c) that account for the three data sources of soil quality.

The spatial models (Equations 1 and 2) are estimated using the maximum likelihood method. The quadratic terms of temperature and spring precipitation never show significant influences in our analysis and are thus removed from the models. For the retained explanatory variables considered in the models I and II (see Table 2), the results of the Lagrange Multiplier test suggest using spatial lag or spatial error models as appropriate models. Based on our theoretical considerations regarding the importance of spatial effects in the case of German land rental prices, the spatial error model is preferable for considering spatial

Table 2. Results of the spatial error models (first order spatial neighbourhood matrix $W^{(1)}$)

	Models[a]											
	Ia		Ib		Ic		IIa		IIb		IIc	
soil index	2.30	***					1.73	***				
dummy loess (=1)			26.07	***					14.22	***		
dummy dystric cambisol (=1)					-16.83	***					-13.64	**
dummy orthic luvisol (=1)					17.72	***					12.61	**
land slope (in %)	-17.10	***	-17.68	***	-15.32	***	-10.46	***	-10.70	***	-8.94	**
spring precipitation (in mm)	-0.12	n.s.	-0.20	**	-0.23	***						
temperature (in °C)	22.14	***	25.92	***	23.89	***	12.50	***	14.88	***	12.87	***
share of grassland							-141.28	***	-160.29	***	-164.65	***
share of rented land	-220.40	***	-198.61	***	-210.73	***	-216.43	***	-199.35	***	-206.41	***
constant	77.47	n.s.	155.01	**	188.20	***	187.48	***	242.65	***	264.96	***
lambda	0.78	***	0.84	***	0.82	***	0.82	***	0.85	***	0.84	***
R^2	0.67		0.54		0.56		0.66		0.56		0.59	
BIC	4625.51		4671.27		4678.32		4556.63		4593.40		4591.77	

[a] Either spring precipitation (model I) or the share of grassland (model II) is considered to be an explanatory variable. Additionally, there are three specifications of both models (a, b, c) accounting for three different data sources of soil quality.
Dependent variable = average (acreage-weighted) land rental price per hectare at the county level; N = 440 counties
*, ** and *** indicate statistical significance at the 10, 5 and 1 per cent significance level, respectively; n.s. indicates not significant
R^2 = square of the correlation coefficient between the observed and predicted data values without adjustment of the error term
BIC = Bayesian information criterion

Source: authors' own calculations based on BGR (2007a), DWD (2007), FAO (2003), FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000), FORSCHUNGSZENTRUM JÜLICH (2009), JARVIS et al. (2008)

autocorrelation and testing our hypotheses. However, the residuals (ε) of the spatial models do not pass a Shapiro-Wilk test for normal distribution which may be partly due to outliers (see Figure A2 in the Annex).

Table 2 (see also Table A2, Annex) presents the results of the spatial error models. The coefficients of the respective variables show the same directions and similar magnitude in all models; the significance levels and models' R^2 differ slightly. Regarding R^2, the models using the soil index as an independent soil variable perform the best. To further analyse the performance of models considering different definitions of the spatial neighbourhood structure, we calculate the Bayesian information criterion (BIC). The models using the first order neighbourhood matrix ($W^{(1)}$) show smaller BIC values than the models using the inverse distance based neighbourhood matrix ($W^{(idw)}$). A BIC difference of at least 10 provides strong evidence that one model fits the data better than another (RAFTERY, 1995), so the models accounting only for adjoining neighbours ($W^{(1)}$) are the preferable models.

It is remarkable that the spatial error coefficient is highly significant for all the model alternatives. This indicates the possible existence of at least one variable that is correlated with different locations in space and determines land rental prices besides the significant variables shown in Table 2. For instance, such factors could be direct payments from the CAP or distances to input and output markets. Unfortunately, the corresponding data were not available for this analysis.

With the exception of the dummy variables orthic luvisol and dystric cambisol (model IIc, $W^{(1)}$), all soil indicators show highly significant results. As expected, productive soils, such as loess or soils with a higher soil index, increase the land rental prices significantly, whereas less productive soils, such as dystric cambisols, show a negative influence. Furthermore, as expected, an increasing average slope of a county's farmland decreases land rental prices. Thus, the different classifications of soil quality do not influence the main results of our Ricardian analysis.

A high share of rented land shows a significant negative influence in our models. An increased share of rented land is assumed to indicate higher competition for farmland which ceteris paribus should lead to higher land rental prices. However, the share of rented land may also determine farmers' capability to pay land rental prices. This capability is lower in case the entire farmland has to be rented (then full costs need to be covered) when compared to a situation where only a few hectares are leased (then shadow prices of the land can be paid). This aspect may explain the land rental price reducing effect of the share of rented land. In addition, land rental prices may also be affected by the number of potential land users. In case of monopsonistic situations, as in some parts of eastern Germany where there are only few big farms renting almost all their land from many small owners, the market power of the big farmers may lead to lower land rental prices.

Regarding the climate variables as well as the variable share of grassland, all models indicate similar results. Increasing spring precipitation (models I) or grassland share (models II) reduces the rental prices for agricultural land. Rental prices tend to be lower for grassland compared to arable land. In Germany, a decline in spring precipitation and an increase in temperature both reduce the grassland share. The models I implicitly allow for the adaptation of the grassland share. In principle, converting grassland or arable land into each other is part of farmers' adaptation possibilities when confronted with different climates. Under German conditions relatively high levels of precipitation lead farmers to abandon arable farming because of increased fungal disease pressure on cereals and other arable crops. Hence, it is likely that the share of grassland is not exogenously given. This may explain why we do not find significant spring precipitation effects any longer when including the grassland share variable into the regression equation. Nevertheless, already in the past, conversion of grassland was partly restricted by law and/or by natural conditions. For example, grassland conversion has always been restricted in nature conservation and water protection areas. Additionally, there is also so called absolute grassland that is definitely not suitable for arable land use (e.g., grassland close to bodies of flowing water or with high groundwater levels; grassland on quite steep slopes). Meanwhile, the transformation of grassland to arable land is also restricted by the cross-compliance requirements that farmers must fulfil to receive direct CAP payments. However, this restriction might be changed in the future. As the extent of past and future conversion possibilities is unclear we considered both alternatives in our models: restricted and unrestricted grassland transformation. In the former case grassland share is seen as an exogenous explanatory variable.

When comparing these findings to the study by LIPPERT et al. (2009), accounting for soil quality and land slope does not remarkably influence the results. The effect of spring precipitation is slightly lower in our models. This effect might be due to the in our case not included dummy variable 'east' that indicated a positive influence of spring precipitation in eastern Germany (LIPPERT et al., 2009).

To estimate the effects of changing climatic conditions on future land rents, we draw on the climate data from the IPCC scenarios. The three selected scenarios (A1B, A2, B1) assume different future climatic conditions. Scenario B1 presents the lowest increase in average temperature (+1.40°C) and in spring precipitation (+32 mm), and scenario A2 describes large changes in climate variables (temperature: +1.55°C; spring precipitation: +56 mm) at the county level (see Table 1). A moderate climatic development is characterised by scenario A1B. Table 3 shows the estimated additional land rents, which increase in all scenarios and model alternatives. With the exception of model Ic the highest increase in total land rent can be found in scenario A2, which shows the highest increase in temperature and spring precipitation. The effect of spring precipitation is less clear when comparing different models; the agricultural profit mainly depends on the temperature increase. Our models show that the weighted average rent increase amounts to 10-17% of the average land rent in 1999. Under a moderate development scenario (scenario A1B) with an average temperature increase of 1.44°C, land rent will rise by 18-30 €/ha UAA and lead to an additional 316-522 million € of land rent. Our results suggest an overall positive impact of climate change on German agriculture, similar to the results in LIPPERT et al. (2009).

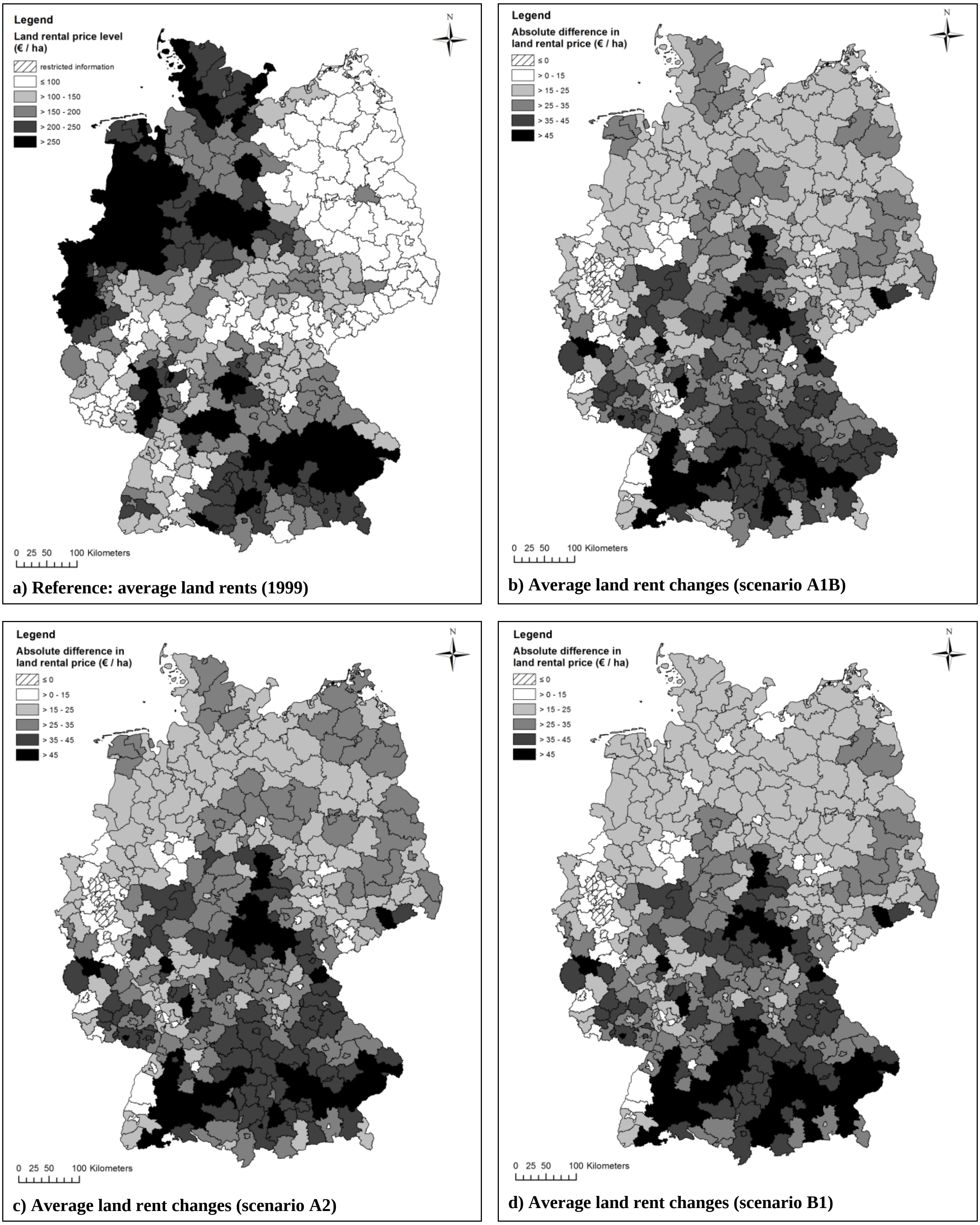
The spatial distribution of land rent changes is shown in Figures 2b-d and 3b-d. These figures present the differences between the estimated future land rents and the estimated land rents in 1999, considering the soil index as indicator of soil quality (models Ia and IIa). Both models indicate that the land rental prices increase from northern to southern Germany, particularly in model I due to the predicted future temperature increase, which shows the same geographic tendency (see Figure 1). For some western regions with a high increase in spring precipitation, model I shows decreasing land rents. Thus, we support the spatially heterogeneous findings by LIPPERT et al. (2009). However, not accounting for a dummy variable 'east', our models do not indicate a strong increase in rental prices in eastern Germany. Due to the presently unfavourable climatic water balance, a rise in spring precipitation (see Figure 1) could have a positive impact on the land rents in eastern Germany. Thus, we consider additional dummy variables indicating extreme precipitation (extreme dry conditions) or low spring precipitation and less productive soils in supplementary analyses. However, these model alternatives do not yield significant results. This is probably due to an insufficient number of corresponding observations.

Table 3. Estimated additional land rent

		Total additional land rent (in million €)[a]			**Weighted average rent increase (€ / ha)[b]**		
		A1B	**A2**	**B1**	**A1B**	**A2**	**B1**
VG	model Ia	478.93	496.12	479.12	27.92	28.93	27.93
	model Ib	521.93	532.72	531.94	30.43	31.06	31.01
	model Ic	451.11	453.87	467.83	26.30	26.46	27.28
CG	model IIa	316.02	336.73	304.61	18.43	19.63	17.76
	model IIb	376.31	400.98	362.72	21.94	23.38	21.15
	model IIc	325.58	346.92	313.83	18.98	20.23	18.30
VG	Lippert et al. (2009)	611.90	597.81	623.14	35.66	34.84	36.32
CG	Lippert et al. (2009)	568.59	599.17	527.21	33.14	34.92	30.73

[a] Total estimated land rent increase for Germany = Σ_i UAA$_i$ × (difference between the estimated land rent after climate change and the estimated land rent in 1999) for the 440 German counties (i = 1, ..., 440), for models I and II using the spatial neighbourhood matrix $W^{(1)}$ cf. Table 2.
[b] The utilisable agricultural areas (UAA$_i$) of the counties are used as weights.
VG = variable grassland: grassland is allowed to be converted into arable land
CG = constant grassland: shares of grassland are to be kept constant
Source: authors' own calculations based on BGR (2007a), FAO (2003), FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000), FORSCHUNGSZENTRUM JÜLICH (2009), LIPPERT et al. (2009), JARVIS et al. (2008), MPI ON BEHALF OF THE UMWELTBUNDESAMT (2006)

Figure 2. Average land rents in 1999 and predicted land rent changes for three IPCC climate scenarios (2011-2040) by county (model Ia, first order spatial neighbourhood matrix $W^{(1)}$)



a) Reference: average land rents (1999)

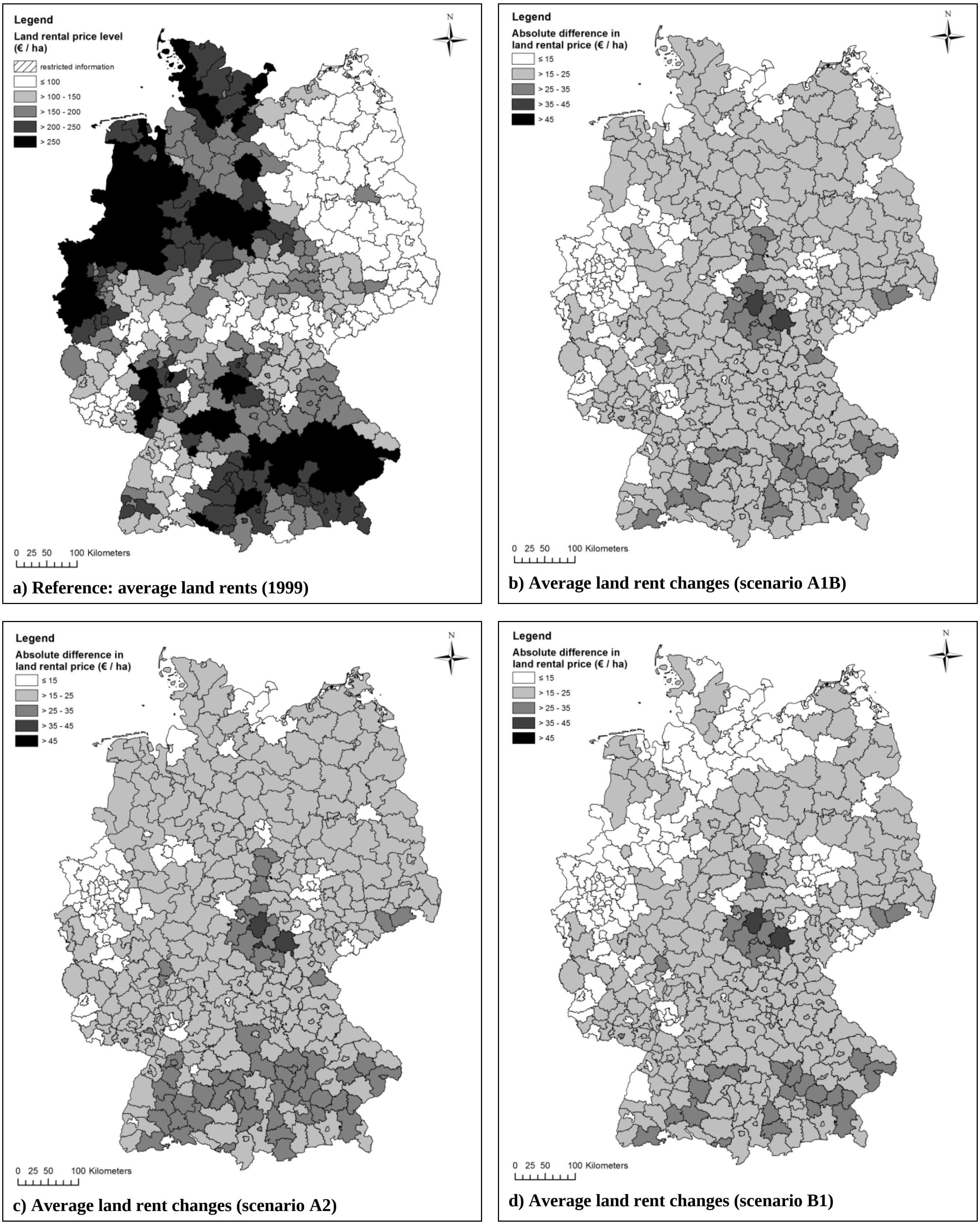
b) Average land rent changes (scenario A1B)

c) Average land rent changes (scenario A2)

d) Average land rent changes (scenario B1)

Source: authors' own presentations based on BGR (2007a), BKG (2010), FAO (2003), FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000), FORSCHUNGSZENTRUM JÜLICH (2009), JARVIS et al. (2008), MPI ON BEHALF OF THE UMWELTBUNDESAMT (2006)

Figure 3. Average land rents in 1999 and predicted land rent changes for three IPCC climate scenarios (2011-2040) by county (model IIa, first order spatial neighbourhood matrix $W^{(1)}$)



a) Reference: average land rents (1999)

b) Average land rent changes (scenario A1B)

c) Average land rent changes (scenario A2)

d) Average land rent changes (scenario B1)

Source: authors' own presentations based on BGR (2007a), BKG (2010), FAO (2003), FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000), FORSCHUNGSZENTRUM JÜLICH (2009), JARVIS et al. (2008), MPI ON BEHALF OF THE UMWELTBUNDESAMT (2006)

To analyse the dispersion of land rents at the county level, we calculate the coefficient of variation using the unweighted average of farms' land rental prices by county (Figure A3, Annex). In large parts of northern and south-eastern Germany, the prices for rental farmland are similar within a county. However, other regions show the opposite situation. To account for such heterogeneous land rental prices within a county, an increase in the spatial resolution would certainly deepen the analysis. Unfortunately, such data were not available for this study.

6 Discussion and Conclusions

In Germany, the rental prices for agricultural land are determined by climate and non-climate factors. Natural production factors, such as soil quality, land slope, spring precipitation and temperature, show significant influences on the land rental prices in our models. Additionally, the agricultural structure, such as the share of rented land, which is distributed quite unevenly within Germany, plays a role. The use of different data sources for soil quality (including worldwide soil data at a low spatial resolution and unique German soil data at a more detailed spatial resolution) and different spatial neighbourhood matrices yield similar results. Thus, the definitions of the spatial neighbourhood matrices tested here and the method to account for soil quality do not influence the main results of the Ricardian analysis in this case. The relevance of spatial error models established by the Lagrange multiplier test hints at a minimum of one additional explanatory variable that is correlated with different locations in space and determines land rental prices in addition to the significant variables found here. In this context, livestock density, direct CAP payments or distances to markets might matter. As indicated by the coefficient of variation, the land rental prices are quite heterogeneous within counties. Thus, an increase in the spatial resolution would certainly deepen the understanding of future climatic effects on agriculture. Unfortunately, such data were not available for this study. Furthermore, a new German agricultural census has been conducted in the year 2010. These new data will be a promising area for research, particularly for repeating our estimation.

To project the future impact of climate change on agricultural productivity, we draw on three IPCC scenarios for the time period 2011-2040. The future climatic conditions for agricultural production will vary by geographic location. Our models show a weighted average increase in land rents of 10-17% compared to the reference situation in 1999 and indicate an increase in land rents. The increments of land rental prices will increase from northern to southern Germany. Thus, we support the findings of LIPPERT et al. (2009) that indicate that future climate change will have an overall positive but spatially heterogeneous impact on the income from agricultural land in Germany. As also indicated by LANG (2007), according to our results German farmers will gain from climate change in the short run. For instance, with respect to the temperature effect our regression results could be summarised into 'the warmer, the better'. However, for obvious biological reasons there must be some kind of temperature optimum in agriculture. If we do not find the corresponding hill-shaped relationship between temperature and the land rental price this is very likely due to the relatively small climatic range within Germany (i.e., we believe that we did not find this effect because of no or only few counties with relatively high temperature levels). Furthermore, we could not consider a variable capturing the frequency of extreme weather events in our regression analysis. Thus, future average temperatures above the range of our observed data may very well have a profitability reducing effect. It is also quite likely (but not analysed in our case) that the predicted increasing future severity and frequency of extreme weather events in Germany will negatively affect agriculture. Thus, in the event of more severe climatic changes and a higher frequency of extreme weather events, income losses for German farmers cannot be excluded.

In response to changing economic and environmental conditions, farmers usually make adaptations (MENDELSOHN et al., 1994). We do not consider adjustments, such as the introduction of new technologies. This omission leads to an underestimation of the real development of rental prices for agricultural land. German farmers may additionally benefit from increasing world market prices due to increasingly unfavourable production conditions in other regions of the world. In contrast, our models may overestimate the real development of land rental prices because farmers will have adjustment and transaction costs due to climate change adaptation.

Nowadays, irrigation is of little importance in German agriculture, so our estimations apply to rain fed farmland. However, irrigation might be used to mitigate climate change damages in increasingly dry districts in the future. Then, different regression equations should be considered for irrigated areas and non-irrigated farmlands (see e.g., SCHLENKER et al., 2005; FLEISCHER et al., 2008).

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Annex

Table A1. Correlation matrix for variables of interest

	Land rental price	soil index	dummy loess (=1)	dummy dystric cambisol (=1)	dummy orthic luvisol (=1)
land rental price	1				
soil index	0.4952	1			
dummy loess (=1)	0.2644	0.5992	1		
dummy dystric cambisol (=1)	-0.4427	-0.4091	-0.2285	1	
dummy orthic luvisol (=1)	0.3060	0.4304	0.3255	-0.4313	1
land slope	-0.3274	-0.0764	-0.0131	0.3144	-0.1445
spring precipitation	0.0240	0.0539	-0.1196	-0.0158	0.2268
mean annual temperature	0.3724	0.2104	0.1445	-0.1030	0.0811
share of grassland	-0.2788	-0.2660	-0.3814	0.1553	-0.1039
share of rented land	-0.5160	-0.0538	0.1147	0.2145	-0.1032
	land slope	**spring precipitation**	**mean annual temperature**	**share of grassland**	**share of rented land**
land slope	1				
spring precipitation	0.5040	1			
mean annual temperature	-0.4378	-0.3244	1		
share of grassland	0.3466	0.6105	-0.3602	1	
share of rented land	-0.1452	-0.5161	0.1014	-0.3004	1

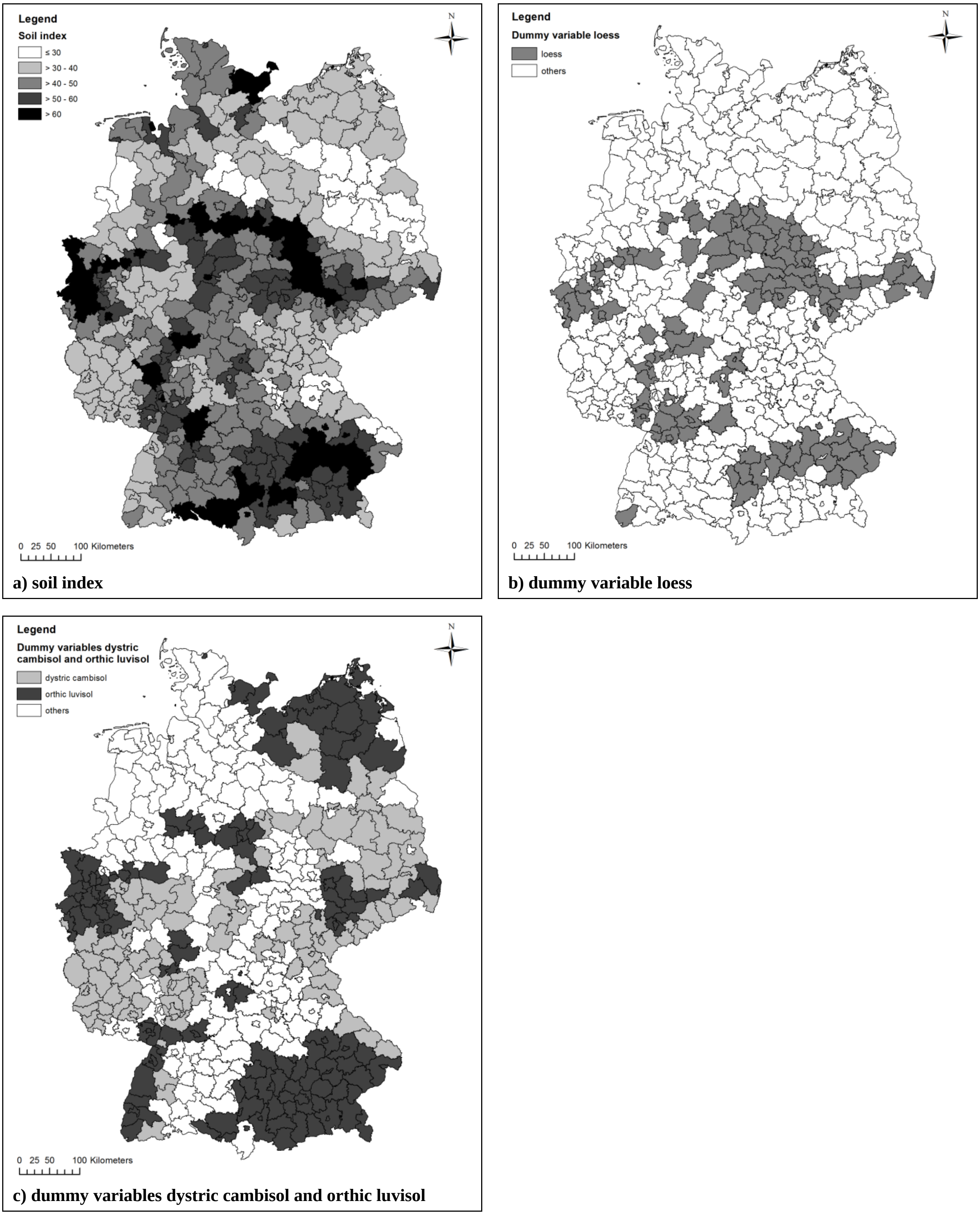
Source: authors' own calculations based on BGR (2007a), DWD (2007), FAO (2003), FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000), FORSCHUNGSZENTRUM JÜLICH (2009), JARVIS et al. (2008)

Table A2. Results of the spatial error models (inverse distance based neighbourhood matrix $W^{(idw)}$)

	Models[a]					
	Ia	Ib	Ic	IIa	IIb	IIc
soil index	3.02 ***			2.53 ***		
dummy loess (=1)		55.16 ***			39.09 ***	
dummy dystric cambisol (=1)			-35.56 ***			-29.84 ***
dummy orthic luvisol (=1)			31.72 ***			21.12 ***
land slope (in %)	-20.74 ***	-24.07 ***	-13.70 ***	-19.20 ***	-20.06 ***	-13.49 ***
spring precipitation (in mm)	-0.18 ***	-0.10 n.s.	-0.25 ***			
temperature (in °C)	17.90 ***	23.74 ***	25.16 ***	12.72 ***	16.76 ***	17.59 ***
share of grassland				-108.80 ***	-118.01 ***	-134.85 ***
share of rented land	-274.15 ***	-278.12 ***	-263.65 ***	-276.02 ***	-287.57 ***	-266.59 ***
constant	122.73 *	176.30 **	162.50 n.s.	185.62 ***	265.26 ***	232.77 **
lambda	0.95 ***	0.96 ***	0.97 ***	0.96 ***	0.97 ***	0.97 ***
R^2	0.67	0.59	0.58	0.69	0.63	0.63
BIC	4790.29	4870.29	4880.78	4742.93	4819.67	4818.14

[a] Either spring precipitation (model I) or the share of grassland (model II) is considered to be an explanatory variable.
Additionally, there are three specifications of both models (a, b, c) accounting for three different data sources of soil quality.
Dependent variable = average (acreage-weighted) land rental price per hectare at the county level; N = 440 counties
*, ** and *** indicate statistical significance at the 10, 5 and 1 per cent significance level, respectively; n.s. indicates not significant
R^2 = square of the correlation coefficient between the observed and predicted data values without adjustment of the error term
BIC = Bayesian information criterion
Source: authors' own calculations based on BGR (2007a), DWD (2007), FAO (2003), FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000), FORSCHUNGSZENTRUM JÜLICH (2009), JARVIS et al. (2008)

Figure A1. Spatial distribution of soil quality at the county level using different indicators



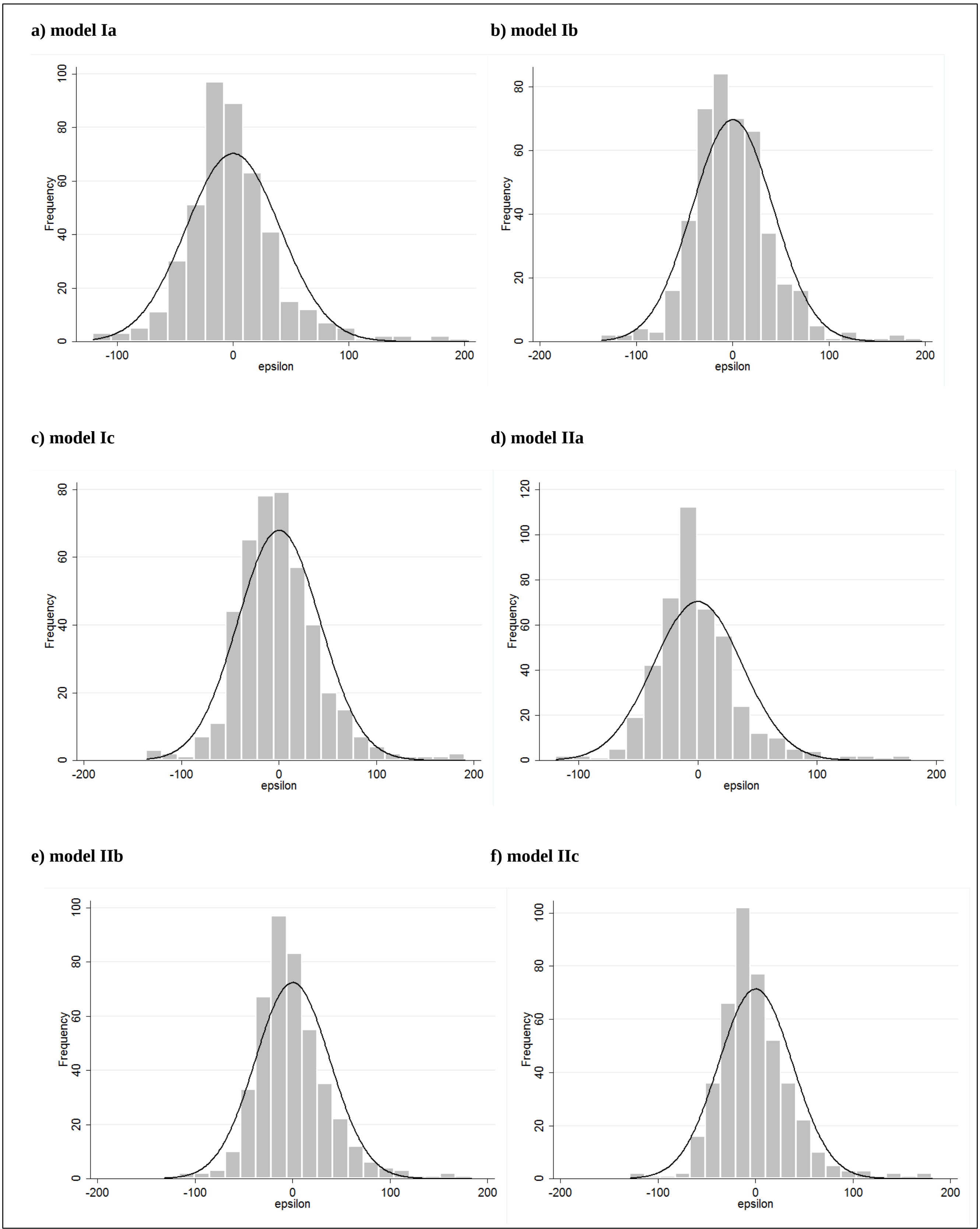
a) soil index

b) dummy variable loess

c) dummy variables dystric cambisol and orthic luvisol

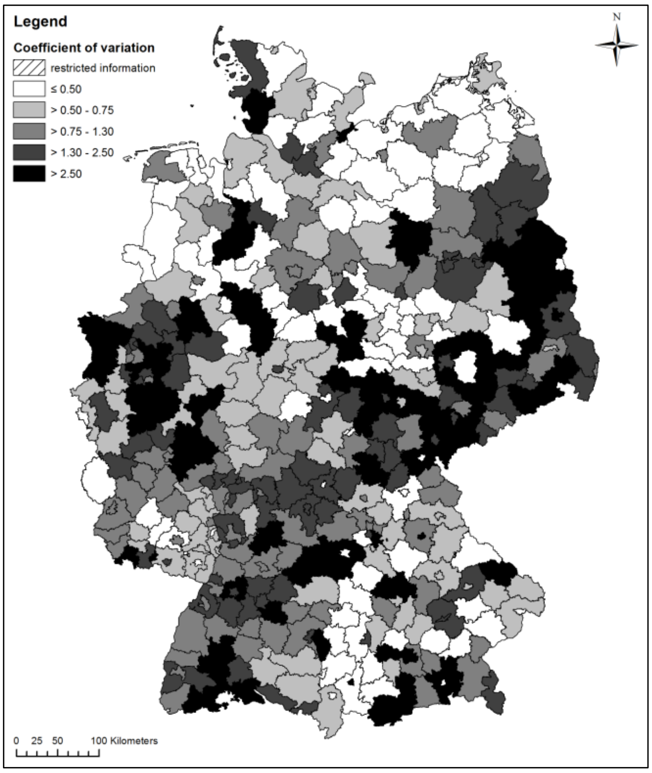
Source: authors' own presentations based on BGR (2007a), BKG (2010), FAO (2003), FORSCHUNGSZENTRUM JÜLICH (2009)

Figure A2. Histograms for the residuals of the finally retained spatial error models and the first order spatial neighbourhood matrix $W^{(1)}$



Source: authors' own calculations based on BGR (2007a), DWD (2007), FAO (2003), FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000), FORSCHUNGSZENTRUM JÜLICH (2009), JARVIS et al. (2008)

Figure A3. Coefficient of variation using the unweighted average of farms' land rental prices by county



Source: authors' own presentations based on BKG (2010), FDZ DER STATISTISCHEN ÄMTER DES BUNDES UND DER LÄNDER (2000)