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The Cost of Climate Change to the German Fruit Vegetation Sector[1].

Claudia Kemfert[2,3] and Hans Kremers[2]

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Abstract:
This paper applies the concept of damage coefficients introduced in Houba and Kremers (2008) to provide an estimate of the cost of climate change - in particular the cost of changes in mean regional temperature and precipitation - to the fruit vegetation sector. We concentrate on the production of apples in the German 'Alte Land' region. The estimated cost of climate change on apple-growing in the 'Alte Land' is dependent on the assumptions regarding developments in the rentability of land not related to climate change in the fruit sector.

JEL Classification: D01, D21, D24, D61, D62, Q12, Q24, Q51, Q54, R32

Keywords: fruit vegetation, Alte Land, climate change, land productivity, land rentability, cost of climate change

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1. Introduction.

There are four main areas in Germany where the climatic conditions are favorable for growing fruit: 'Das Alte Land' under Hamburg in Lower Saxony, and regions in Saxony, Rheinland-Pfalz, and Baden-Württemberg. These favorable conditions are mainly based on the climatic conditions, i.e. on the temperature, and precipitation in these areas which lead to a favorable productivity of the soil in the orchards. Recent developments in the regional climate threaten to bring significant changes to these areas. On the one hand, the increase in temperature observed during the last decades results in more beneficial conditions for the production of fruit, in particular apples. On the other hand, higher temperatures also attract parasites such as the apple coiler that cause a significant decrease in apple-growing.

We assume that land is used most profitably in the orchard sector where it is being used as a production factor. This might change due to climate change influences, which will have its influence on this profitability and hence on the rentability. The latter may cause farmers in the 'Alte Land' area to sell off their land for alternative purposes, or choose to grow apple species that are more resistant to the new climatic conditions, as this might prove more profitable.

This paper tries to estimate the cost of climate change on apple-growing in the 'Alte Land' region in Germany. To this end, we apply the concept of damage coefficients introduced in Houba and Kremers (2008) to model the possible beneficial consequences of climate change - as foregone damages - into computable general equilibrium models. This approach allows us to distinguish between economic developments and the explicit consequences of climate change in the production sector. It is the difference between the two associated scenarios that provides an estimate for the cost of climate change in the German orchard sector. It may be obvious that this cost estimate depends to a large extent on the assumptions underlying the economic developments in the orchard sector and on the specification of the damage function.

Section 2 of this paper describes the production in the orchard sector using a simple microeconomic formulation as a production function and it includes the damage coefficients from Houba and Kremers (2008). Section 3 estimates a possible scenario of land productivity over time which is assumed to represent the economic development in fruit production. Dependent on the assumptions underlying the economic development, we determine the influence of climate change variables, such as the regional minimal temperature during the blossoming period in spring and regional mean precipitation levels, on land productivity from the difference between the actual productivity levels and the economic productivity levels. Section 4 determines an estimate for the cost of climate change and its relation to developments in the rentability of land in the German orchard sector. Section 5 concludes.

2. Production in the orchard sector and climate damage.

Economics determines how to allocate scarce resources among a set of alternatives. Scarcity implies an insufficient availability of resources to cover all. The choice for one alternative means that one foregoes any of the other alternatives, i.e. one foregoes the net cost associated with these alternatives. The (net) costs associated with the next best alternatives are referred to as the *opportunity costs* of the chosen alternative. When we talk of the 'costs of climate change' we refer to its opportunity costs for the economy.

To be able to compute the costs of climate change, we should state an alternative to a scenario on the development of productivity of land that includes the environmental damages related to the climate. Such an alternative scenario only consists of the economic developments, if no climate change takes place. Hence, we have to define an economy-only scenario for the German fruit vegetation sector. The economy consists of a simple model of the German fruit production activity, being a simple production function.

Standard microeconomic theory models any production activity in the economy using a production household. Such a production household is characterized by its production function that refers to its technology and its behavior which is described by profit maximization. We refer to Varian (1992) as the standard reference on microeconomic theory and to Kemfert (1998) who estimates the substitution elasticities of production functions in Germany. A production function describes the household's production technology. It transforms units of each combination of possible input goods into an amount of the output good. Let us assume that y units of a certain output good can be produced from x_i units of each input good $i = 1, \ldots, n$. A production technology can then be written as $y = f(x_1, \ldots, x_n)$, where f is a continuous function, referred to as the production function. We assume that f exhibits so-called constant returns to scale. Under this assumption, take any factor $t > 0$. Then, $f(tx_1, \ldots, tx_n) = t\,f(x_1, \ldots, x_n)$, hence, multiplying all input amounts with the same factor t increases the sector's output with the same factor. Compare this with a production technology that exhibits increasing returns to scale (>) or decreasing returns to scale (<).

The combination of input and output amounts into a vector is often referred to as an input-output vector or a production vector. The producer determines the production vector as the vector that maximizes his profits. Let $p_1, \ldots, p_n$ be the prices of all inputs and let p_0 define the output price, assuming good 0 is the output good. Let p denote the price vector and p_{-0} denote the input price vector. Then, profit maximization comes down to determining output levels y and input levels $x_1, \ldots, x_n$ on the production function f such that profits p_0y - $(p_1x_1 + \ldots + p_nx_n)$ are maximized. Notice that, under the assumption of constant returns to scale, it is not straightforward to solve this optimization problem. But, we could redefine the amount x_i of input good i as the amount of input good i per unit of output good. Total demand of input good i can then be written as x_iy. Profit maximization is then equivalent to determining the amounts x_i of each input good i that minimize the costs $c(p_{-0}) = p_1x_1 + \ldots + p_nx_n$ per unit of output, while taking prices p as given by the market.

Solving the cost minimization problem results into an input demand function $a_i(p)$ of input good i per unit of output. Profit can then be rewritten as $[p_0 - c(p_{-0})]\ y$, and it may be obvious that the profit maximization problem only has a solution for good prices p such that $p_0 \leq c(p_{-0})$. In case $p_0 < c(p_{-0})$, then profit maximization implies that the producer will cease production, hence $y = 0$ is optimal. In case $p_0 = c(p_{-0})$, then profit maximization implies that the producer will produce anything the market demands, hence any $y > 0$ is optimal. This condition is often referred to as the 'Non-positive profits condition', and we turn to this condition in Section 4 when we discuss the rentability of land in the fruit orchard sector.

In applications of microeconomic theory, such as computable general equilibrium models, often so-called Constant-Elasticity-of-Substitution functions are used to specify the production function f. Then, $f(x_1, \ldots, x_n) = [(a_1x_1)^{(1-\sigma)/\sigma} + \ldots + (a_nx_n)^{(1-\sigma)/\sigma}]^{\sigma/(1-\sigma)}$, which results into a per unit output cost function $c(p_{-0}) = [(p_1/a_1)^{1-\sigma} + \ldots + (p_n/a_n)^{1-\sigma}]^{1/(\sigma-1)}$. In these functional forms, the parameter a_i refers to the productivity of input good i in the production of the output good. A high value of this parameter implies that a unit of input good i is highly productive. The parameter σ denotes the elasticity of substitution between each pair of input goods. This substitution elasticity parameter is assumed to be constant. If there is one percent of input good i less available in the production of a unit of the output good, then the producer should include σ percent more of another input good j to keep the output level unchanged. This paper applies the special case of $\sigma = 0$, when the production function reduces to the Leontief specification $f(x_1, \ldots, x_n) =$

$\min\{a_1x_1, \ldots, a_nx_n\}$ with appropriate unit cost function $c(p_{-0}) = (p_1/a_1) + \ldots + (p_n/a_n)$. This Leontief specification is the simplest specification available, leading to a linear cost function. It assumes no substitution possibilities between the input goods. The input goods are complimentary, meaning that a unit of the output good can only be produced by a fixed proportion determined by the cost minimizing amounts of each input good.

Damages in production related to the climate have two sources, the production technology itself is affected (for example, crops and fruit trees are sensitive to temperature changes) or certain inputs are degraded by climate change (for example, precipitation requires more irrigation or less productivity of a single drop of water). We follow Houba and Kremers (2008) in modeling the consequences of climate change on the economic behavior of the producer through the introduction of damage coefficients $d_i > 0$ into the production function - hence $f(x_1, \ldots, x_n) = d_0 \min\{(d_1a_1)x_1, \ldots, (d_na_n)x_n\}$ and associated cost function $c(p_{-0}) = p_1/(a_1d_1) + \ldots + p_n/(a_nd_n)$. The damages d_0, d_1, ..., d_n refer to climate related damages in the productivity of the technology - indexed with 0 - and of the input goods i in the production sector - indexed with i. With the introduction of these damage coefficients, we separate the economy related influences on productivity from the influences related to the climate. The former influences are then represented by changes in the productivity parameter a_i. A damage coefficient d_i can take a value in (0, 1] to represent a deteriorating effect or it can take a value $d_i \geq 1$ in case the effect is beneficial. In case $d_i \in (0, 1]$, it means that commodity i's effectiveness decreases from x_i to d_ix_i, where $d_i = 1$ corresponds to no damage done on the effectiveness of good i in the production process. Otherwise, d_ix_i can be seen as an increase in commodity i's effectiveness. Similarly, we also introduce $d_0 > 0$ to indicate the overall impact on the output good. All impact coefficients are treated as additional parameters in the producer's optimization programs that are, similar to prices, taken as given by the economic agent.

We refer to Kemfert (2007) and to Tol (2002a) or Tol (2002b) for the estimation of climate related damages. This paper assumes that $d_k = 1$, $k = 1, \ldots, n$, hence abstracting from possible climate influences on the input goods in the production function, and concentrate on the determination of d_0.

3. The estimation of a cost function including climate damages.

The first column of Table 5 in Appendix A provides the annual production of apples in the Alte Land region from 1973 until 2007, which we obtained from Ellinger and Görgens (2007). Apples are only a part of the types of fruit produced in the 'Alte Land' region. Table 1 compares the production of apples in this region, refered to as 'Niederelbe' with the production of apples in the rest of Germany, as well as with the rest of the EU15 regions and the Non-Member states (NMS). We present an overview of the production of apples (in 1000 ton) in the 27 EU member states, EU-27, distinguished among the New Member States (NMS), the former 15 EU member states, EU-15, Germany, and the Niederelbe region. This table depicts the significance of Germany, and in particular the 'Alte Land' region as an important apple producer.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Niederelbe	270	310	320	308	163	222	246	292	301	304
Rest of Germany	N.A.	N.A.	N.A.	614	600	596	699	733	647	648
Germany	977	1036	1131	922	763	818	945	1025	948	952
Rest of EU-15	6422	7360	7870	6592	6359	6096	5995	6147	5703	5850
EU-15	7669	8706	9001	7514	7122	6914	6940	7172	6651	6802
NMS	2627	2528	3225	3579	3150	3423	3546	3149	3177	1721
EU-27	10296	11234	12226	11093	10272	10337	10486	10321	9828	8523

Table 1: Production of apples (in 1000 ton) in EU-27 according to EU states and regions (see Ellinger and Görgens (2007)).

The second column of Table 5 in Appendix A provides a sequence of the acreage of land that is dedicated to apple orcharding in the 'Alte Land' from 1973 until 2007. Table 2 compares this acreage (in *ha*) dedicated to apples with that used for growing other types of fruit, taken from Görgens (2007). It shows that the vast majority of its land is dedicated to apples. We therefore concentrate our analysis on apple orcharding.

	1981	1987	1992	1997	2002	2007
Apples	9175	9092	8879	8811	7277	8363
Pears	698	532	438	298	268	319
Sweetcherries	682	552	522	501	437	538
Sourcherries	798	470	241	102	39	23
Plums	243	154	155	160	190	248
Total	11596	10800	10235	9872	8211	9491

	1981	1987	1992	1997	2002	2007
Apples	79.10%	84.20%	86.80%	89.30%	88.60%	88.10%
Pears	6%	4.90%	4.30%	3%	3.30%	3.40%
Sweetcherries	5.90%	5.10%	5.10%	5.10%	5.30%	5.70%
Sourcherries	6.90%	4.40%	2.40%	1%	0.50%	0.20%
Plums	2.10%	1.40%	1.40%	1.60%	2.30%	2.60%
Total	100%	100%	100%	100%	100%	100%

Table 2: Fruit growing acreage (in *ha*) specified according to type of fruit (see Görgens (2007)).

Let us assume that the production of apples can be described with a production function with only land ('L') priced at p_L (in €/*ha*) as its input good. Then, we find the following cost function from the previous section

$$d_0 c(p_L)y = (a_L)^{-1} p_L y,$$

in the case of a Leontief technology with a productivity parameter a_L (in ton per *ha*) for land. Using this linear production function associated with the cost function, $y = a_L x_L$, we can determine the value $\hat{a}_L$ for a_L using the formula,

$$\hat{a}_L = y/x_L,$$

where x_L is the demand for land (in *ha*) in the production sector. The parameter a_L can hence be determined as the productivity of land in the apple production sector. In the third column of Table 5 in Appendix A, we have computed the results for $\hat{a}_L$ by combining the data in the first and second column of this table. Notice that, on land use, we only have data for the time periods 1981, 1987, 1992, ..., 2007 available from Görgens (2007). The slanted numbers for in-between time periods were obtained under the assumption that land use adjusts linearly within these periods.

We estimate the development of the productivity of land in the 'Alte Land' region over time using the following regression equation,

$$\ln\left(\frac{a_{L,t}}{1-a_{L,t}}\right) = \ln b + f \ln(t-1972) + u_t,$$

where u_t denotes a normally distributed error term. Table 3 provides further results on the estimation.

	Estimate	St. Error	t-value	Pr(>|t|)
Constant	-4.39882	0.14107	-31.18300	< 2E-16***
Time	0.25264	0.05099	4.95500	2.110E-05***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 ' . ' 0.1 ' ' 1

Table 3: Estimation results for the dependence of land productivity on time, in the 'Alte Land' region: Estimation, Standard Error, t-value, and significance level. Further estimation results show a null deviance of 3.7899 on 34 degrees of freedom, a residual deviance of 2.1733 on 33 degrees of freedom, and the AIC equal to 8.0568. The number of Fisher Scoring iterations was 2.

This results into the following estimates $b = 0.0123$ and $f = 0.2526$. These estimation results turn the relation between land productivity and time into

$$\underline{a}_{L,t} = \frac{0.0123}{0.0123 + (t-1972)^{-0.2526}}.$$

Figure 1 depicts the estimated relation between land productivity and time, while the fourth column of Table 5 provides the underlying estimated values. This relation between productivity and time models land productivity as an increasing process over time with decreasing gains over time. Notice that we may possibly improve upon the estimation results in Table 3 by choosing the base year, here 1972, in an optimal way.

Figure 1 also provides a comparison between the estimated productivity of land and the observed productivity of land in 1000 ton per *ha*. We assume that the estimated productivity of land develops according to economic influences, for example following improved techniques in apple orcharding over time. The latter estimated function hence provides what we assume to be the economic development for the 'Alte Land' region. The differences between the observed productivity of land and this estimated productivity in Figure 1, we assume to be the consequence of climate change impacts, in particular due to changes in regional minimum temperature over the blossoming season, and in mean percipitation levels.

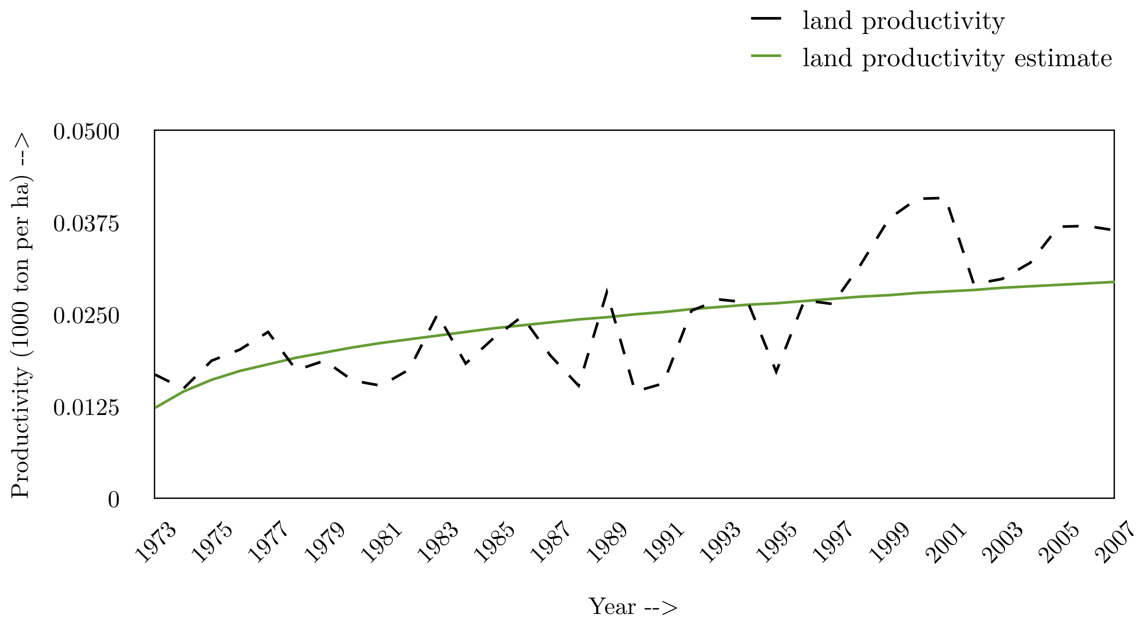

Figure 1: The productivity of land in 1000 ton apples per *ha* in the 'Alte Land' region compared to the estimates**.**

The differences between estimated and observed productivity of land in Figure 1 leads us to define the damage coefficient $d_{0,t}$ as

$$d_{0,t} = a_{L,t} \;/\; \underline{a}_{L,t},$$

for each period t = 1973, ..., 2007. We depicted the values of $d_{0,t}$ in the fifth and last column of Table 5 in Appendix A. Average damage is 1.027 which indicates a productivity improvement of 2.7% over the period from 1973 until 2007. Damage variates between a minimum of 0.578 and a maximum of 1.462.

The climate damage coefficient d_0 is the consequence of the development in levels of certain climate related variables, W_j, j = 1, ..., m, such as for example regional temperature, precipitation, sun radiation, or sea-level rise. The relation between these climate variables and damage to the economy is given by a relationship h_j such that $d_0 = h_j(W_1,..., W_m)$.

We regard minimum regional temperature during the blossoming season, W_{Temp} and annual average or mean precipitation W_{Prec} as climate variables. The blossoming season for apples mainly refers to spring time, which we take to be the months of March until June on the northern hemisphere. In Table 6 of Appendix B, we have obtained data on the regional minimum temperature during the blossoming season (second column) and precipitation (third column) over the period of 1973 to 2005. These data represent the regionalized data from the IPCC scenario A1B in combination with WETTREG. These climate data are combined with the calculated damages in Table 5 of Appendix A to obtain an estimation of a simple specification of the damage function *h*, which we assume to be linear in the regional minimum temperature W_{Temp} and mean percipitation W_{Prec}. Table 4 describes the extensive results of the estimation.

	Estimate	**St. Error**	**t-value**	**Pr(>|t|)**
Temperature	0.00976	0.03505	0.27800	0.7830
Precipitation	0.01494	0.00103	-14.51900	2.250E-15***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 ' . ' 0.1 ' ' 1

Table 4: Estimation results for the damage function *h* on regional minimum temperature during the blossoming period and on precipitation, in the 'Alte Land' region: Estimation, Standard Error, t-value, and significance level. Further estimation results show a null deviance of 35.6985 on 33 degrees of freedom, a residual deviance of 2.8299 on 31 degrees of freedom, and the AIC equal to 18.5936. The number of Fisher Scoring iterations was 2.

This estimation results in the following damage function:

$$d_{0,t} = 0.0098\, W_{\text{Temp}} + 0.015\, W_{\text{Prec}}.$$

Figure 2 depicts the estimated damage function in comparison with the values of the damage coefficients obtained from Table 5 over the period between 1973 and 2007 in Appendix A.

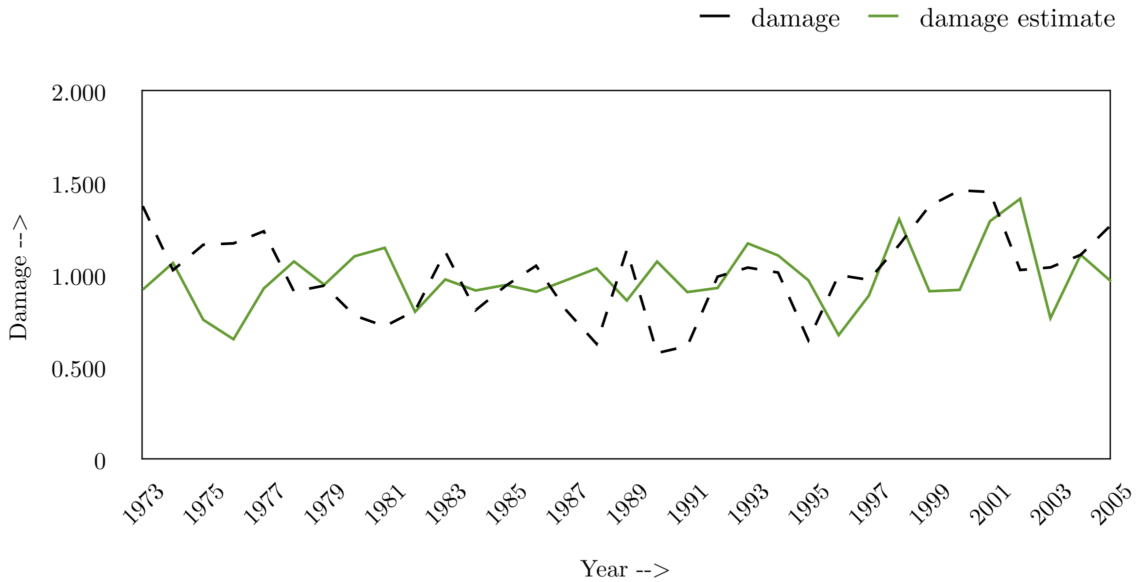

Figure 2: The damages of climate change in the 'Alte Land' region compared to the estimates obtained from the damage function.

4. Rentability and the cost of climate change.

Modern land-use theory developed itself from the works of David Ricardo in Ricardo (1951-73) and von Thünen (1910). According to Ricardo (1951-73), land use is determined by the private production decisions of farmers, each of whom chooses a profit maximizing land-use pattern from a set of restricted production possibilities given prevailing input and output prices. Changes in land-use arise if the production possibilities available to a producer alter or if the relative profitability of available production possibilities changes. The latter will occur if input or output prices change, whereas the former may occur if planning or policy contraints tighten or relax, if technological advances change the production function(s), or if resource constraints faced by individual producers alter. Climate change has its consequences through both channels. It directly changes the production function through changes in the productivity parameter which we modeled by including a damage coefficient into the production function. On the other hand, changes in productivity of land results in changes in the cost of production, and hence on the rentability of the use of this land in the production sector. The cost of climate change can be expressed by the change in rentability of land used in the fruit orcharding sector.

Associated with each time *t*, we can postulate the following relationship between the price $p_{0,t}$ of the output good, and the price $p_{L,t}$ of land:

$$p_{0,t} = (d_{0,t}a_{L,t})^{-1}p_{L,t}.$$

This relation was derived in the previous section under the assumption of a production function with only land as its input good. It determines the price of the output good in each period t as a function of the price of land in t.

We determine the rentability of land in the fruit sector. Land is a production factor with alternative economic uses. Given current prices, we can list these alternative uses of land according to profitability. Following a neoclassical economic approach, the land will be used for the economic activity where it is most profitable. Then the land price p_L will be set such that profits equal zero. Allocating land to another activity would result in a loss making activity under the given price of land. Hence, the profit per unit of land is taken away completely by the height of the land price. This makes the price of land p_L to be equal to the profit per *ha* of land.

Let us assume that land is most profitably used in the current production of apples at current market prices p_0 and p_L. Then we can rewrite aforementioned equation to obtain the rentability of land in terms of the output price:

$$p_L/p_0 = d_0 a_L,$$

hence it expresses the rentability of land in terms of tons of apples per *ha*. This equation distinguishes economic effects a_L from climate related effects d_0 on the rentability of land.

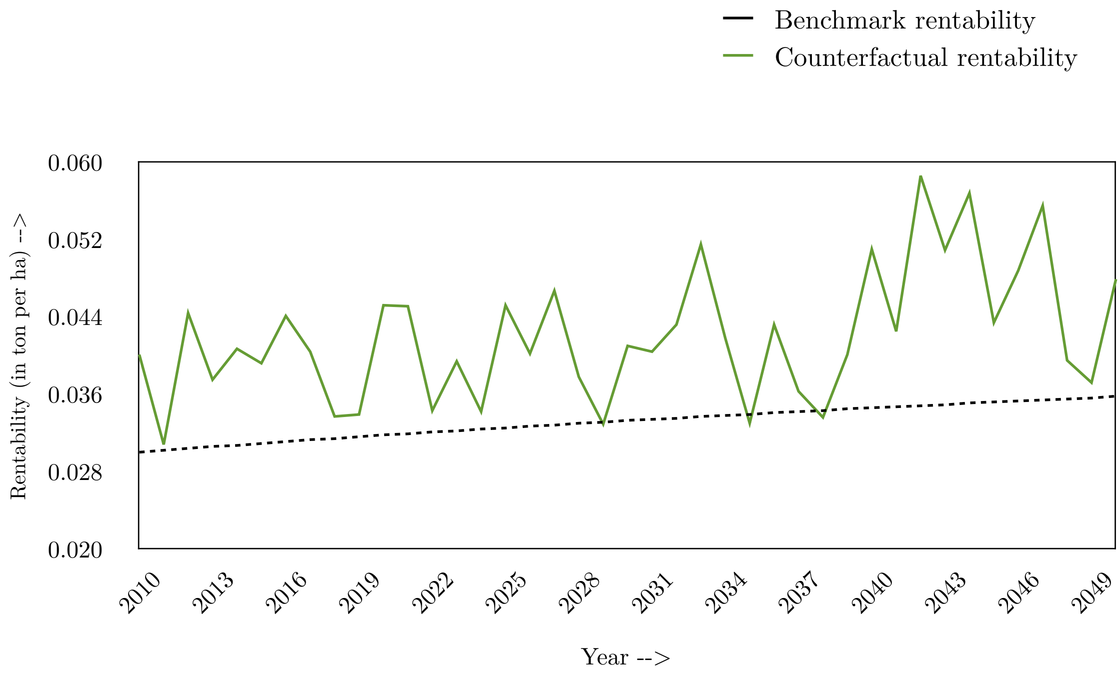

Figure 3: The development of rentability (in ton/*ha*) according to the Benchmark scenario in comparison to the development of rentability according to the Counterfactual scenario.

To determine the cost of climate change, we need to distinguish two scenarios. One scenario only entails the economic development in the production of apples given by the sequence $a_{L,t}$, t = 2010, ..., 2050, and where all damage coefficients $d_{0,t} = 1$. Let us call this the benchmark scenario, and rentability develops itself according $(p_{L,t}/p_{0,t})^{\mathrm{B}}$ in ton apples per *ha* of land. Table 8 in Appendix D provides the values for $a_{L,t}$ in the second column. These values also present the rentability under the benchmark scenario due to the assumed unit damage coefficients. Another scenario includes the damages related to climate change, following the variation in regional minimum temperature during the blossoming season and precipitation over time, given by the damage function estimated in the previous section. Then, rentability contains non-unit damage coefficients. Table 7 in Appendix C computes the damage coefficients $d_{0,t},\ t = 2010, ..., 2050$. Average damage over this period is 1.2681 which indicates a productivity improvement of 26.8% over the period from 2010 to 2050. Damage varies between a minimum of 0.9715 and a maximum of 1.6835.

These values are repeated in the first column of Table 8 in Appendix D which, in combination with the land productivity values $a_{L,r}$, compute the productivity values in the last column of Table 8. Let us call this scenario the counterfactual scenario and rentability develops itself according $(p_{L,t}/p_{0,t})^{\mathrm{C}}$ in ton apples per *ha* of land. Figure 3 depicts these two scenarios. The total area between these curves represents the cost of climate change in this sector.

The cost of climate change for the 'Alte Land' production sector in period t then equals the difference between total counterfactual rentability and benchmark rentability, hence

$$-[(p_{L,t}/p_{0,t})^{\mathrm{C}} - (p_{L,t}/p_{0,t})^{\mathrm{B}}]\ \underline{x}_L.$$

In Figure 3, the first part of this formula is the difference between counterfactual and benchmark rentability of land for each time t. We have chosen for the average use of land in the production of apples during period 1981 to 2007, $\underline{x}_L = 8760$, see the second column of Table 5 in Appendix A. This simple approach to incorporate land-use changes may be sufficient for the benchmark scenario. One could improve on this approach by allowing climate change induced land use changes over the period 2010 to 2050 in the computation of counterfactual total rentability of land.

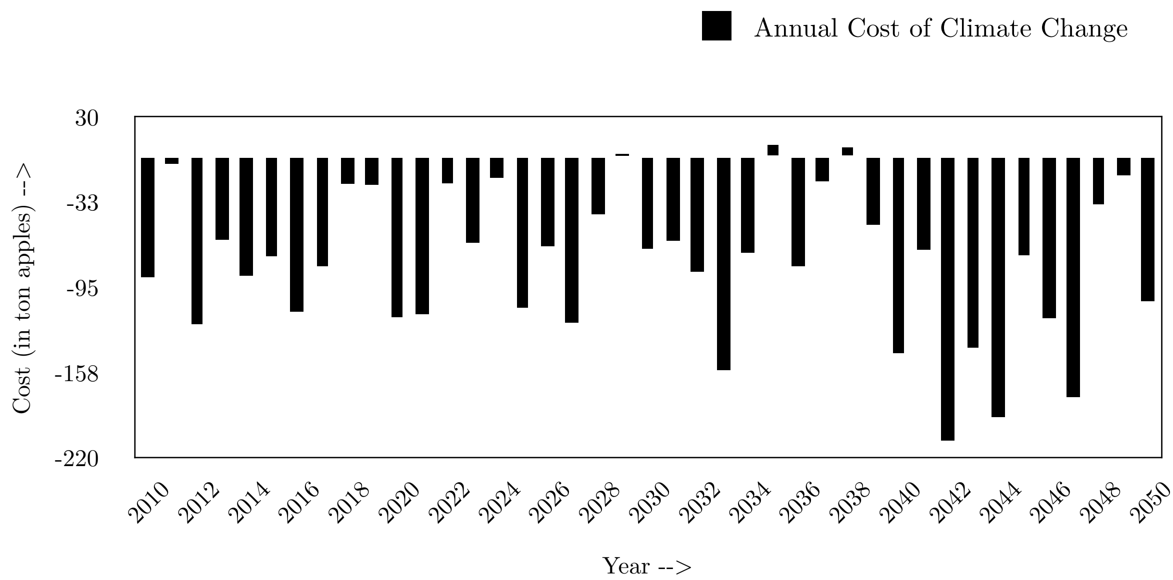

Figure 4: The cost of climate change in each period t measured in tons of apples.

Figure 4 computes the cost of climate change for the 'Alte Land' region in each period t from 2010 until 2050. These costs are denominated in the output price. This means that in each period t, Figure 4 shows the loss in tons of apples due to climate change in the 'Alte Land'.

The last figure shows that the apple production in the 'Alte Land' benefits from climate change. The increase in minimum temperature during the annual blossoming season and in mean precipitation levels according to the A1B scenario leads to productivity levels that are in general higher than what can be explained by economic or technological progress.

5. Conclusions

This paper computes the cost of climate change in a production sector. We referred to climate change as changes in the regional minimum temperature during the blossoming season and mean regional precipitation. The paper concentrates on apple growing in the 'Alte Land' region south of Hamburg in Germany as the example production sector. We modeled the activities in this sector using a simple linear production function with only land as an input. Economists regard the opportunity costs of choosing one alternative over another. The cost of climate change on this production sector can be calculated as the difference in (net) costs between two scenarios, a benchmark scenario that only considers the economic development regarding land productivity in the apple growing sector and a counterfactual scenario that introduces damages related to climate change.

To be able to split developments about the productivity of land in the production sector into economic developments and climate change, we introduced so-called damage coefficients associated with the usual land productivity parameters in the production and cost function of the apple growing production sector. The damage coefficients are used to introduce the climate influence into the production function and cost function. We estimate a simple damage function that relates these damage coefficients to the climate variables mean regional temperature and precipitation.

The cost of climate change are then calculated as the difference in (net) costs between a benchmark scenario where we set the damage coefficient equal to one, and a counterfactual where the damage coefficient varies with climate through a damage function. The estimation of these costs are significantly determined by the specification of the damage function and by the presumed economic development in the sector.

A comparison with the cost of climate change in the other apple growing regions could reveal more about the future economic viability of apple growing in Germany. Apple growing in the 'Alte Land' proves to remain a rentable production sector in the future. Figure 4 even shows that climate change as temperature and precipitation changes are beneficial to this sector. As was shown in the previous section, the cost of climate change relates intricately to changes in the rentability of land use in this sector following climate change. In which region will the rentability changes be so significant that land is being shifted to more rentable production sectors in the immediate surroundings. To that end, we should compare the rentability of land in the growing with the rentability of land in the other neighboring sectors.

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Appendix A

Year t	Production y_t	Acreage $x_{L,t}$	Productivity $\hat{a}_{L,t}$	Est. Prod. $\underline{a}_{L,t}$	Damage $d_{0,t}$
	(ton)	(ha)	(1000 ton per ha)	(1000 ton per ha)	
1973	157660	*9430*	0.0167	0.01215	1.3759
1974	139540	*9398*	0.0148	0.01444	1.0280
1975	174515	*9367*	0.0186	0.01597	1.1663
1976	187970	*9335*	0.0201	0.01716	1.1736
1977	209110	*9303*	0.0225	0.01813	1.2395
1978	160400	*9271*	0.0173	0.01897	0.9119
1979	171940	*9239*	0.0186	0.01971	0.9441
1980	146650	*9207*	0.0159	0.02037	0.7818
1981	139240	9175	0.0152	0.02098	0.7235
1982	159360	*9161*	0.0174	0.02153	0.8079
1983	227470	*9147*	0.0249	0.02204	1.1281
1984	166680	*9134*	0.0182	0.02252	0.8103
1985	197630	*9120*	0.0217	0.02297	0.9434
1986	224170	*9106*	0.0246	0.02340	1.0523
1987	175160	9092	0.0193	0.02380	0.8096
1988	137380	*9049*	0.0152	0.02418	0.6279
1989	251510	*9007*	0.0279	0.02454	1.1378
1990	128960	*8964*	0.0144	0.02489	0.5780
1991	138710	*8922*	0.0155	0.02522	0.6164
1992	225200	8879	0.0254	0.02555	0.9929
1993	238900	*8865*	0.0269	0.02585	1.0423
1994	235000	*8852*	0.0265	0.02615	1.0152
1995	151320	*8838*	0.0171	0.02644	0.6476
1996	236140	*8825*	0.0268	0.02672	1.0016

Year t	**Production y_t**	**Acreage $x_{L,t}$**	**Productivity $\hat{a}_{L,t}$**	**Est. Prod. $\underline{a}_{L,t}$**	**Damage $d_{0,t}$**
	(ton)	(ha)	(1000 ton per ha)	(1000 ton per ha)	
1997	232000	8811	0.0263	0.02699	0.9757
1998	270000	*8504*	0.0317	0.02725	1.1652
1999	310357	*8197*	0.0379	0.02750	1.3767
2000	320000	*7891*	0.0406	0.02775	1.4615
2001	308400	*7584*	0.0407	0.02799	1.4529
2002	280491	7277	0.0385	0.02822	1.3658
2003	222400	*7494*	0.0297	0.02845	1.0431
2004	245700	*7711*	0.0319	0.02867	1.1112
2005	291600	*7929*	0.0368	0.02889	1.2730
2006	300700	*8146*	0.0369	0.02910	1.2684
2007	303755	8363	0.0363	0.02931	1.2392

Table 5: Annual production of apples y_t, in ton, (see Ellinger and Görgens (2007)) in the first column, fruit growing acreage $x_{L,t,}$ in ha, (see Görgens (2007)) for t = 1981, 1987, 1992, 1997, 2002, 2007, in the second column. The slanted light printed numbers in the second column are obtained by linear extrapolation of the collected non slanted numbers. The third column computes the productivity of land, $a_{L,t}$, in ton per ha, from the previous two columns. The fourth column computes the fitted productivity of land, $\underline{a}_{L,t}$, in ton per ha, while the fifth column compares fitted with computed value to obtain a damage coefficient $d_{0,t}$.

Appendix B

Year	damage	temperature	precipitation	Year	damage	temperature	precipitation
1973	1.3759	1.3576	60.8640	1991	0.6164	3.1074	58.8300
1974	1.0280	1.3948	70.5620	1992	0.9929	2.1869	60.9320
1975	1.1663	1.3219	49.9270	1993	1.0423	0.0037	78.5550
1976	1.1736	-1.9045	44.9550	1994	1.0152	2.6943	72.4120
1977	1.2395	2.5911	60.4820	1995	0.6476	0.3911	64.8930
1978	0.9119	2.0680	70.6410	1996	1.0016	-1.5588	46.2200
1979	0.9441	0.6564	63.1030	1997	0.9757	1.9596	58.3040
1980	0.7818	-0.0576	73.9180	1998	1.1652	2.2505	85.8900
1981	0.7235	2.5588	75.2820	1999	1.3767	2.7288	59.3810
1982	0.8079	0.9247	53.0870	2000	1.4615	2.7595	59.8500
1983	1.1281	2.1604	64.0620	2001	1.4529	0.8314	86.0620
1984	0.8103	-0.8158	61.9690	2002	1.0290	1.9284	93.5170
1985	0.9434	0.7301	62.9830	2003	1.0431	0.8683	50.7850
1986	1.0523	0.0850	60.9170	2004	1.1112	1.4650	73.4580
1987	0.8096	-3.0532	67.1830	2005	1.2730	-0.0428	64.8020
1988	0.6279	0.8321	68.9220	2006	1.2684		
1989	1.1378	3.6653	55.3910	2007	1.2392		

Table 6: Calculated damage coefficients $d_{0,t}$, regional minimum temperature during spring (March until June) W_{Temp} (in degrees Celcius), and precipitation W_{Perc} (in mm), for the periods $t = 1973, \ldots, 2007$.

Appendix C

Year	Damage	Temperature	Precipitation	Year	Damage	Temperature	Precipitation
2010	1.3375	4.6471	86.1322	2031	1.2114	3.5942	78.4119
2011	1.0191	0.1489	67.8453	2032	1.2878	3.2272	83.7466
2012	1.4632	3.7816	95.0783	2033	1.5314	2.7655	100.2896
2013	1.2283	2.5251	80.2402	2034	1.2378	0.5531	82.1580
2014	1.3247	0.4414	88.0265	2035	0.9715	-0.1767	64.8800
2015	1.2697	1.6613	83.5580	2036	1.2693	1.9058	83.3726
2016	1.4187	2.1696	93.1603	2037	1.0601	4.9634	67.4292
2017	1.2936	-2.9670	88.1791	2038	0.9776	1.6476	64.0946
2018	1.0724	3.1218	69.4558	2039	1.1656	3.9756	75.1109
2019	1.0741	1.8469	70.3969	2040	1.4767	3.1450	96.3931
2020	1.4237	1.7602	93.7610	2041	1.2252	5.0163	78.4007
2021	1.4145	3.1936	92.2164	2042	1.6835	3.0596	110.2361
2022	1.0696	1.7235	70.1826	2043	1.4588	4.0575	94.6037
2023	1.2241	3.2104	79.5084	2044	1.6229	5.9600	104.3003
2024	1.0552	2.1036	68.9713	2045	1.2352	2.5752	80.6617
2025	1.3889	3.6604	90.2037	2046	1.3836	3.0962	90.2186
2026	1.2304	1.7482	80.8846	2047	1.5691	3.8080	102.1189
2027	1.4245	2.0392	93.6347	2048	1.1118	6.7917	69.6795
2028	1.1469	1.5416	75.4532	2049	1.0437	1.9872	68.2790
2029	0.9926	0.7452	65.6859	2050	1.3396	3.4274	87.0651
2030	1.2318	1.8238	80.9302				

Table 7: Predicted damage coefficients $d_{0,t}$, obtained from the A1B scenario values for regional minimum temperature W_{Temp} (in degrees Celcius) during the blossoming season, and precipitation W_{Perc} (in mm), for the periods $t = 2010 ..., 2050$.

Appendix D

	Rentability (B)	Rentability (C)	Annual cost		Rentability (B)	Rentability (C)	Annual cost
2010	0.0299	0.0400	-88.4260	2031	0.0333	0.0403	-61.6774
2011	0.0301	0.0307	-5.0461	2032	0.0334	0.0431	-84.3195
2012	0.0303	0.0443	-122.8951	2033	0.0336	0.0514	-156.3181
2013	0.0305	0.0374	-60.9480	2034	0.0337	0.0417	-70.2213
2014	0.0306	0.0406	-87.1840	2035	0.0338	0.0329	8.4588
2015	0.0308	0.0391	-72.8161	2036	0.0340	0.0431	-80.1347
2016	0.0310	0.0440	-113.6937	2037	0.0341	0.0362	-17.9476
2017	0.0312	0.0403	-80.1733	2038	0.0342	0.0335	6.7268
2018	0.0313	0.0336	-19.8845	2039	0.0344	0.0400	-49.8444
2019	0.0315	0.0338	-20.4373	2040	0.0345	0.0509	-143.9869
2020	0.0317	0.0451	-117.5271	2041	0.0346	0.0424	-68.2525
2021	0.0318	0.0450	-115.5779	2042	0.0347	0.0585	-207.9159
2022	0.0320	0.0342	-19.5093	2043	0.0348	0.0508	-140.0478
2023	0.0321	0.0393	-63.0918	2044	0.0350	0.0567	-190.7839
2024	0.0323	0.0341	-15.6110	2045	0.0351	0.0433	-72.2677
2025	0.0324	0.0451	-110.5367	2046	0.0352	0.0487	-118.2821
2026	0.0326	0.0401	-65.7820	2047	0.0353	0.0554	-176.0460
2027	0.0327	0.0466	-121.7450	2048	0.0354	0.0394	-34.6808
2028	0.0329	0.0377	-42.3174	2049	0.0355	0.0371	-13.5924
2029	0.0330	0.0328	2.1433	2050	0.0357	0.0478	-106.0498
2030	0.0332	0.0409	-67.3543				

Table 8: Calculated Benchmark and Counterfactual rentability $p_{L,t}/p_{0,t}$, and resulting annual Cost = -[$(p_{L,t}/p_{0,t})^C$ - $(p_{L,t}/p_{0,t})^B$] $\underline{x}_L$, for the periods t = 2010, ..., 2050, where $\underline{x}_L$ = 8760 *ha*.