The Effects of Climate Change on Output

Bachelor Thesis

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I. Introduction

In recent years large populations across numerous countries on the globe became increasingly aware of the phenomenon of climate change. The consequences, such as temperature rising and changes in precipitation can have a major influence on the economy. As existing research on the effects of temperature and precipitation on the income of countries is scarce, we want to examine the causal relationships closely. Also, winning and losing countries from climate change shall be identified based on their geographic locations. Whereas some countries benefit from the consequences of climate change, for many countries it is believed that climate change and its consequences poses a major problem.

In the Netherlands, for instance, climate change and its effects play a controversial role. As a country that lies four meters below the ocean, it is threatened by a rising sea level and increasing precipitation. For the second half of the 21st century, serious consequences are being forecasted. Especially for the country's low lying areas a sea level rise of 0.5-1 meters (OECD, 2008) or a river discharge due to more extreme temperatures and precipitation events can have severe consequences including flooding of regions, loss of land, shifting of coastal lines, shifting of living and economic activity. If the sea level and precipitation change drastically "it is questionable whether conventional techniques can be used to maintain the current level of safety." (Netherlands Environmental Assessment agency, 2006)

A recent example believed to be linked to the phenomenon of climate change by scientists is the heat wave over large parts of Europe in 2003. In their fourth assessment report on climate change the Intergovernmental Panel on Climate Change assessed the impacts of climate change. From June to mid August 2003 temperatures in southern and central Europe were 3° to 5° Celsius higher than usual with mean temperatures of 6° to 7° more in June. Accompanied by precipitation deficits this led to droughts and a 30% reduction in gross primary production over Europe. "This reduced agricultural production and increased production costs, generating estimated damages of more than 13 billion" (Intergovernmental Panel on Climate Change, 2007). Next to the economic damages, the heat wave had severe negative impacts on nature and human health.

The externalities that arise from climate change and their costs are inevitable and affect the whole society. Therefore, it is worth studying their origins as well as their economic consequences.

The problem behind the described phenomena is the emission of greenhouse gases and the consequential global warming effect, the "process that naturally warms the earth" (Thomas, Callan, 2007: 257). 83% of the greenhouse gases consist of energy-related carbon dioxide (CO2) emitted from industrial and economic activities. The scientific process of the increasing temperature of the earth's surface takes place as follows. Sunlight hits the earth's surface and is re-mirrored back into the atmosphere, where it is absorbed by CO2 and other greenhouse gases (Thomas et al., 2007: 257). As the concentration of gases increases, more warmth is absorbed and that way captured between the surface of the earth and the atmosphere. An increased amount of CO2 thus causes a rise in temperature as well as changing weather conditions around the globe.

Various problems for nature, humans, and industry are associated with global warming. For nature these include ocean level rising, large desertification, changes in rainfall, and storminess. For example, sea levels rise from melting glaciers affecting coastal regions, and lead to a loss of dry- and wetland. Already dry areas devastate with even higher temperatures and no rainfall; whereas cold areas might benefit from slightly higher temperatures, with plants growing faster and thus higher crops. Agricultural damage risks are accompanied by an increase of insects, and animal species will adapt or migrate. A temperature rise and a change of weather conditions in combination with these phenomena again affect agriculture, forestry, energy use, water resources, human health, species, ecosystems, landscapes, and many other aspects of nature, which can have both negative and positive impacts on agricultural and industrial productivity in different regions. Moreover, it is frequently maintained by scientists, that climate change has a direct impact on the productivity of human beings. Temperature rises influence human health in terms of heat stress, spread of diseases, poor air quality (summer smog), and an increase of allergies (Netherlands Environmental Assessment agency, 2006). Scientists argue that if the temperature rises, people become less productive. Many chains of causal relationships are thus triggered by the emission of carbon dioxide.

Precipitation changes the water levels on the mainland. Major changes in precipitation, resulting from climatic changes, for instance, influence river floods, the river bed, and the catchment area which influence the use of the surrounding land and flood protection (Tol, 2002a). Moreover, it influences vegetation and crops.

The described consequences have severe impacts on the economy. The affected areas of agriculture, forestry, fishery, and the production of goods and services are components of the gross domestic product (GDP). If returns from those production areas decline (or for some countries rise), the consumption expenditures of the country will change and the GDP amends. The crucial query from an economic perspective is thus in which way climate change and its consequences, caused by increasing concentrations of CO2 emissions, influence GDP.

The respective increase or decrease of the latter can be an indicator, or even a direct measure for the costs and benefits of climate change. This research shall examine the impact of climate change and its phenomena of temperature and precipitation changes in particular, on GDP and identify winning and losing countries based on their geographic locations.

In order to investigate the diverging effects of climate change on GDP, it is essential to differentiate between countries with different geographic sites. Countries in northern and southern latitudes, for instance, suffer from different types and magnitudes of consequences and can have different abilities to cope with the consequences.

It is possible that high-latitude countries, including many European and North American countries, benefit from temperature increases as sectors such as vegetation and crops are influenced positively. For instance, if average temperatures are relatively cold and rise slightly towards the optimal crop temperature, vegetation grows faster yielding higher crops and better land productivity. Also, many northern countries are rich so that their capacity to deal with the effects of climate change is large. Abnormal developments and events in nature can be balanced out by costly counter measures. For instance, an extremely dry summer period can be balanced out by a good irrigation system or when a natural catastrophe destroys large land stripes, resources are available to re-erect everything in a short time period.

On the other hand, countries in lower latitudes, in southern Europe, Africa, Latin America, and Oceania, which are characterized by high temperatures already, are likely to be influenced negatively by further increases. Already dry areas suffer from more severe and longer periods of drought drying out natural water reserves and preventing crops to grow. Furthermore, the welfare level in many southern countries is lower, making the effects larger. The poorer southern countries do not have the exact means described above to counter undesirable consequences from climate change. “Agricultural investment opportunities decline significantly and the resources of these countries to develop alternatives are limited” (Molle, 2006: 190).

II. Literature Review

Research on the economic effects of temperature elevation and precipitation on GDP is available to a limited extent. Nordhaus (1994) gives a good theoretical overview by presenting the effects of climate change as estimated by experts. The more recent empirical studies that were completed can be divided into three categories. A first group of studies employs statistical methods to estimate the damage costs of climate change in cost functions.

Another group of studies is concerned with the effects of climate change on single components of income. The physical effects for different categories, such as agriculture, ecosystems or the sea level, are analysed singularly. A third group actually analyses the aggregate effects of climate change on GDP, however, their approaches differ from the one used in this paper. Eventually an overview of many studies conducted is given by Tol (2009).

A sound technical introduction to the topic of the impacts of climate change is given by Nordhaus (1994) who conducts expert interviews with economic, social and natural scientists. It is agreed by all researchers that global warming poses high risks to natural ecosystems and human civilization which has severe consequences for economic performance. The more the CO2-concentration in the air increases, the more temperature rises, the higher the impact on the economy. It remains uncertain, however, how severe these impacts are. Generally, it is assumed by many that the economic impacts of climate change primarily concern sectors covered by the standard national accounts, such as food or manufacturing. Effects on human health and ecosystems have not been taken into consideration in these studies. Furthermore, analysts found that there are substantial differences in the impacts between developed and developing countries; for the former the levels of income generally increase, whereas for the latter it decreases.

In the first group of studies, the authors use statistical methods to examine the damage costs of climate change. Tol (1995) establishes a cost function of climate change to express the damage cost. Therefore, he considers eight loss categories, among others, dryland- and wetland loss, agriculture, morbidity rates, and natural hazards that contribute to the size of the damage cost in a respective area. He establishes great losses due to climate change, and CO2 emissions in particular in each of the loss categories. However, he also stresses the great uncertainty that still exists when making estimations about the effects of climate change.

In the paper by Mendelsohn, Schlesinger, and Williams (2000), they develop a forecasting model to predict impacts of temperature and precipitation on economies. They make separate calculations for various sectors and countries and use a climate-response function to calculate the respective damages or benefits. The projections as well imply that "high-latitude countries are less sensitive to temperature increases than low-latitude countries" (Mendelsohn et al., 2000: 37).

A further number of studies deal with the impacts of climate change on different components of GDP. In two papers, Tol (2002a and 2002b) analyses and estimates the influence of temperature rise on various components of GDP - agriculture, forestry, ecosystems, sea level rise, human mortality, energy consumption, and water resources. The impacts are estimated and valued in monetary terms and comprise various countries and regions. He establishes that “a 1 °C increase in the global mean surface air temperature would have, on balance, a positive effect on the OECD, China, and the Middle East, and a negative effect on other countries” (Tol, 2002a).

Maddison (2003) examines the impact of temperature rise in 60 countries. He includes environmental variables in the demand equations for five consumption goods and establishes that consumption is indeed influenced by climate. The main finding is that the impact of temperature on income from consumption good production differs for countries in different latitudes. “Climate change is likely to confer […] considerable benefits on cold northern countries […] whilst in hot tropical countries any increase in temperatures is likely to reduce welfare and result in a large change in the cost of living in those countries” (Maddison, 2003: 27).

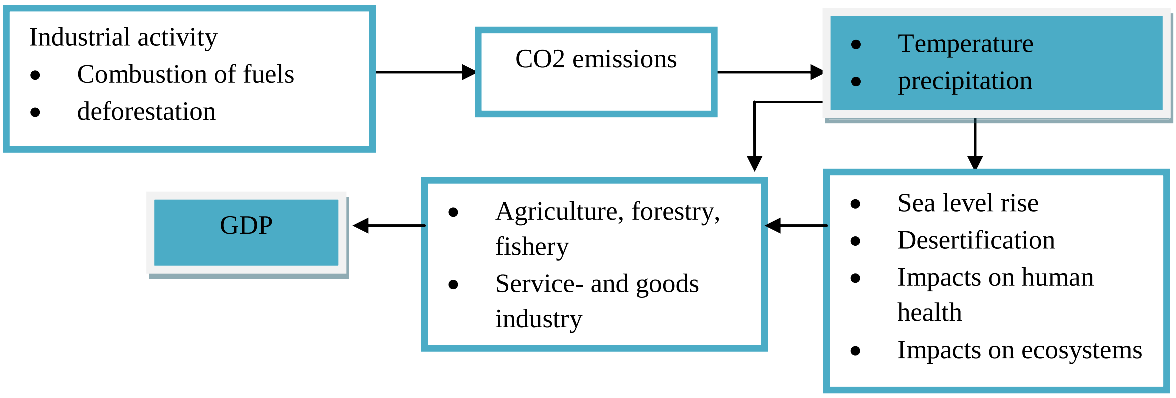
Several researchers examine the causal relationship of temperature and income; all researches, however, have a different research aim and focus of the research on different aspects. Maddison and Rehdanz (2005) examine the social cost of climate change by examining the impacts of temperature and precipitation on happiness. They do so by estimating and comparing the impact of temperature and precipitation on happiness and real GDP. They confirm a significant impact of temperature and precipitation on the two variables and further establish that in terms of both happiness and GDP “high-latitude countries […] might benefit from temperature changes. Countries already characterized by very high summer temperatures would most likely suffer losses from climate change” (Maddison and Rehdanz, 2005: 111).

Nordhaus (2006) finds a negative relationship between climate change, that is, temperature rise, and GDP and furthermore examines which role geography plays in this relationship. He clusters the globe into grid cells according to latitude and longitude and estimates income per capita in each grid cell. He proves that “output per capita rises with distance from equator” (Nordhaus, 2006: 3512)

Eventually, an overview of various empirical studies conducted is given by Tol (2009). He aggregates the estimates of previous studies of the effect of temperature on components of GDP and summarizes the total economic effects. These are throughout negative; a rise in temperature goes along with a decrease in GDP. On the other hand, he establishes that all studies find a different impact of climate change on the best-off and the worst-off regions. Low-income countries are usually worse off, whereas high income countries are often better off.

From existing literature it can be suspected that there is a causal relationship between CO2 emissions, temperature rise, and precipitation, and GDP. Thereby, variables such as sea level rise and desertification are intervening variables, as they inherently result from temperature rises. The relationships with its causal effects and intervening variables are summarized in Figure 1.

Figure 1: How CO2 emissions affect GDP



In previous research it has been investigated what the relationship is between CO2 emissions and GDP per capita. Also, there are several studies existing that investigate the impacts of temperature rise and precipitation on different components of the standard national accounts, for instance, on agriculture. Moreover, there exist studies that use statistical methods to estimate the damage costs resulting from climate change. From the studies that analyse the impact of climate change on GDP, one study analyses social costs and the other neglects political borders of countries as the estimations are only based on latitudes and longitudes.

So far, empirical evidence for the aggregate economic effects resulting from climate change for different countries and with recent data does not exist. This research shall examine the aggregate economic impacts of climate change and CO2 emissions whilst differentiating between the impact on northern and southern countries. To address this research, we will first examine the effects of temperature and precipitation on GDP. It is suspected that temperature and precipitation have a significant impact on GDP per capita. Secondly, we will establish whether temperature and precipitation have different impacts on northern and southern countries. We hypothesize that there is a significant difference between northern and southern countries.

The aim of the research is to estimate the total economic costs (or benefits) of climate change and its consequences in terms of GDP, a monetary value. As all variables that are influenced in the various sectors are included, the outcome is a direct estimate of the aggregate costs and benefits of climate change for countries. For the losing countries, it can be regarded as an empirical proof of the substantial costs of climate change in terms of losses in GDP. Likewise, it indicates benefits in monetary terms for possible winners. Hence, from an economic perspective the outcome will have striking policy implications. If an overall negative impact should hold to be true, the urgency to reduce CO2 emissions is confirmed. Moreover, it is important if there is a difference between countries as this would require different actions for different countries. In the following sections we will first describe the data, the methodology, present the results of the research and their robustness, discuss their interpretation and policy implications, and finally conclude.

III. Data

For the investigation how precipitation and temperature influence GDP a linear function will be used that is dependent on temperature and precipitation. These are the two major consequences resulting from increasing CO2 emissions identified in the literature. They cause increasing desertification, rise in sea levels, storms etc. which represent consequences from the former, and should therefore not serve as explanatory variables for GDP. To establish a causal relationship between the dependent and the two major independent variables, seven control variables are included in the equation. The GDP per capita growth rate describes how the nation’s economic well-being evolves over time, and indicates “the accumulation of means of production” (Burda and Wyplosz, 2005). As better means to grow lead to more GDP growth, the respective changes in the growth rate are one explanatory variable for the income of a country. The annual inflation rate, the change in the level of prices, and the annual rate of unemployment, the rate of people seeking for work, are further macroeconomic variables explaining GDP. The higher the two rates, the more loss of output and income to the economy. Urban population indicates how urbanized a country is. As industrial and economic activity to a large extent take place in the cities, an urban population commonly indicates a higher production, hence, higher GDP. The population density per square kilometer is a similar measure, the higher the density, the more urbanized the area is. The average compensation of employees indicates the value of the work the population is doing. For instance, in a country that primarily operates in the service industry, the populations receives higher salaries than in a country with predominantly agriculture or industrial production, thus the overall GDP is higher. The life expectancy at birth indicates how developed a state is in terms of technology and medically; the level of development is usually high when the economy is highly developed, therefore, GDP is relatively high. The selected variables are chief influential variables for GDP and are chosen in accordance with the research of Maddison et al. (2005). The variables used are summarized in table 1.

table 1: definition of variables

GDP	GDP per capita
Temperature	Average temperature per year (°C)
Precipitation	Average rainfall per year in mm
GDP growth	Annual GDP per capita growth rate (%)
Inflation	Annual inflation rate (%)
Compensation	Average income per capita
Population density	Population density in persons per square kilometer
Life expectancy	Life expectancy at birth in years
Urban population	Percentage of the population living in urban areas
Unemployment	Annual rate of unemployment (%)
Latitude	Average latitude per country in degrees

The study of the impact of temperature and precipitation on GDP is carried out for 30 OECD countries (see appendix A.1) for the years from 1960 to 2008. The advantage of examining OECD countries only is that OECD countries have by definition a certain standard of welfare and are economically far developed. Factors that also determine the GDP, such as welfare or the level of economic development, are thus approximately equalized and do less bias the results than when undeveloped countries are also included. The likelihood of multicollinearity or correlation with other factors is lower. This way it is possible to study more precisely whether temperature and precipitation are influencing factors on GDP in different geographies.

The data for temperature for Austria, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, The Netherlands, Norway, Portugal, Sweden, and Switzerland is retrieved from the European Climate Assessment and Dataset (ECA&D) project. The data was only available on a daily basis and was summarized as the average temperature per year per country. For the countries Spain, New Zealand, Turkey, Denmark, United States, Australia, Canada, Japan, Czech Republic, Hungary, Republic of Korea, Mexico, Poland, Slovak Republic, Belgium, and United Kingdom the data was retrieved from the National Climatic Data Center of the US department of Commerce. Here the data was available on a monthly basis and therefore summarized as the average temperature per year per country. For most countries the temperature of the capital city was taken, only in cases where these data were not available or where the capital was very far away from the average latitude of the country, a city that is close to the average latitude was taken.

The data for precipitation for all countries was as well taken from the National Climatic Data Center. The monthly data for the cities was summarized as the average precipitation per year per country. Data for the average latitude of the countries was obtained from the resources of Purdue University. All other data for GDP and control variables were taken from the World Development Indicators (WDI Online) database of the World Bank. The data for GDP is based on constant US dollars with the base year 2000. Missing data was estimated for the control variables GDP per capita growth, compensation of employees, population density, and life expectancy at birth. These variables were extrapolated based on the assumption that their trend is linear. For other variables such as unemployment and inflation extrapolation was not possible as these variables are exposed to great fluctuations during the years. All data are based on scientific observations and thus reliable. Table 2 shows the descriptive statistics for the climate and control variables.

table 2: descriptive statistics for climate and control variables

	N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
GDP	1371	1109.86	56358.12	15690.36	9613.87
Temperature	1487	2.58	21.55	10.87	4.06
Precipitation	1477	58.08	1962.92	636.43	268.47
GDP growth	1440	-14.57	27.43	2.82	3.23
Inflation	1131	-1.88	139.66	8.93	13.52
Compensation	1245	3.11E8	2.17E13	2.34E11	1.64E12
Population density	1470	1.36	501.52	123.97	116.33
Life expectancy	1468	50.26	82.59	73.52	4.73
Urban population	1470	27.70	97.36	69.1	13.87
Unemployment	745	1.50	23.90	7.30	4.01
Latitude	1500	23.25	63.45	46.61	9.61

IV. Methodology

For the econometric analysis we will conduct an ordinary least square regression analysis using GDP in a function dependent on temperature, precipitation, and the control variables. GDP and the climate variables are in logs to indicate the growth rate of GDP in elasticities and to meet the assumptions for the regression analysis of a linear function. The log-linear function has the following form:

$$\ln(GDP)_{i,y} = \beta_0 + \beta_1 * \ln(temperature)_{i,y} + \ln(precipitation)_{i,y} + \beta_5 * X_{i,y} + \alpha_i + \mu_y + \varepsilon_{i,t},$$

where i stands for the country and y for the year. Country- and year- specific effects are included to account for the heterogeneity between countries and years. α_i represents a fixed effect for the country that accounts for unobserved factors that affect GDP on the regional level. μ_y represents a fixed effect for the year and represents changes over time, such as technology improvements. X stands for a vector of control variables.

We account for the business-as-usual by applying the differences-in-differences approach. Looking at GDP per capita per country over the years one can establish a constant growth for all individual countries from 1960 to 2008. It is crucial to estimate how much the GDP would have grown due to other developments and in how far the growth is attributable to changes in temperature and precipitation. In order to establish this we add fixed effects for countries and years. Fixed effects for countries account for heterogeneity of unobserved factors that affect GDP on the national level. The intercept can be different for different countries due to inherent structural differences in savings, population growth, etc. The United States, for instance, have the highest GDP overall, and thus are likely to have the highest intercept when controlling for country and time effects. Fixed effects for years account for changes in time series. GDP was lower in earlier times and gradually increased, partly due to technology improvement, higher environmental standards and policies over the years.

In order to investigate the second research question, whether the variables chosen have different impacts on GDP in northern and southern countries, we include a variable for the absolute average latitude of the country. In particular, we include the variable of the average latitude and the interaction effect of the average latitude and the average temperature of a country. Moreover, we test the research question by creating dummy variables for two sub samples of northern and southern countries.

The regression of the temperature and precipitation-output relationship is based on the crucial assumption of homogeneity of slopes for all examined countries. It is assumed that even if countries differ in their intercepts and time trends, they all follow the same slope and have the same turning points (Aslanidis, 2009:15, and Dijkgraaf et al., 2005:1). As the assumption has frequently been challenged for the CO2 emissions-output relationship in literature, it is worth examining it for the temperature and precipitation-output profile. Scientists argue that “countries differ in initial conditions or structural parameters such as savings, technological change (in abatement) and population growth rates. Such divergences across countries (over time) would not be adequately captured by country- and time specific fixed effects” (Dijkgraaf et al., 2005:1). We will establish whether the homogeneity assumption holds for the countries examined, that is, if the temperature and precipitation-output profiles of different countries vary or not.

V. Results

The results of our estimations are depicted in table 3. We estimate the equation in four steps. First, a function with GDP dependent on average temperature and precipitation (i), subsequently, we add control variables (ii), a fixed effect for countries (iii), and eventually a country- and year fixed effect (iv). It is striking that in the first model the estimated relation between average temperature and GDP is negative; an increase in temperature evokes a decrease in GDP. For precipitation and GDP the relationship is positive, an increase in precipitation leads to an increase in GDP. The relationships persist when adding control variables to the model.

When estimating the full model, however, the picture changes completely. It is revealed that GDP is explained by the variety between countries and years to a large extent. When adding country fixed effects, the coefficient for average temperature becomes positive, and the coefficient for average precipitation becomes insignificant, indicating that precipitation does not explain changes in GDP. For temperature it implies, that a certain extent of the effect of temperature on GDP can be explained by inherent differences between countries. The overall relationship is positive for temperature, only the intercepts with the y-axis differ between countries. Thus, correcting for unobserved variety between countries is very important.

Eventually, the full model is estimated with country- and year fixed effects. The effect of the average precipitation per year is insignificant. The coefficient for the average temperature per year is significant at the 1% level; a rise in temperature by 10% causes an increase in GDP by 8.4%. This number is slightly smaller than in the third specification without the fixed effect for years. This is due to the fact that we account more correctly for the business-as-usual as part of the positive effect found can be explained by time related effects, for instance, by technology improvement over the years. In the consecutive steps the r-square values gradually increase; the full model represents the best approximation as it has the highest r square value of 0.992. The test for multicollinearity within the models is negative, all variance inflation factors are close to 1, indicating that information of the variables chosen is not captured in another variable. Thus, the variables do not correlate and the independent variables chosen explain the dependent variable well.

Note that we also estimated the model with country and year fixed effects and no other control variables. The full estimation results can be found in table 7 in the appendix. The coefficients for average temperature and precipitation are both insignificant. The fact that in the models with the control variables the coefficients are significant shows that these models are preferable from a statistical point of view. Moreover, it is an indicator for the correctly chosen control variables.

From our control variables GDP growth, the compensation of employees, urban population, and unemployment are significant in the full model. Population density and life expectancy are not significant. These results are not in line with the results of Maddison et al. (2005), as the control variables chosen had a significant impact on GDP per capita. Possibly, urbanization is a better indicator for a high GDP than population density and possibly the life expectancy is not informative for this group of countries as they are all economically high developed countries and life expectancy does not mirror the technological and medical standards.

table 3: estimation results

	(i) temperature and precipitation		(ii) control variables		(iii) country fixed effect		(iv) country- and year fixed effects	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Constant	6.827	.297***	-2.854	.504***	3.667	.205***	9.712	.435***
Ln(temperature)	**-.484**	**.047*****	**-.308**	**.034*****	**.138**	**.032*****	**.084**	**.032*****
Ln(precipitation)	**.581**	**.046*****	**.493**	**.037*****	**.011**	**.014**	**.010**	**.012**
GDP growth			-.014	.005***	.003	.001***	.002	.001*
Inflation			-.004	.001***	.000	.000*	.000	.000**
Compensation			-5.259E-14	.000***	5.444E-15	2.952E-15*	2.597E-14	2.858E-15***
Population density			-8.260E-5	.000	.001	.001*	9.607E-5	.001
Life expectancy			.128	.006***	.075	.002***	.003	.005
Urban population			.009	.001***	.007	.002***	.005	.002***
Unemployment			-.028	.003***	-.013	.001***	-.010	.001***
Fixed effect countries[1]					yes		yes	
Fixed effect years							yes	
R square	.146		.763		.989		.992	
Observations n	1344		672		672		672	

- Dependent variable: ln(GDP)
- *significant at 10%
- **significant at 5%
- ***significant at 1%

- [1] All estimates for fixed effects are available on request.

To investigate the second question, whether the impact of temperature and precipitation is different for northern and southern countries, we add two terms to our specification, the variable for average latitude and the interaction effect of latitude and temperature. The summary of our estimations is depicted in table 4. The full regressions can be found in the appendix in table 8. We observe that all three variables of temperature, latitude, and their interaction are significant, the coefficient for precipitation is insignificant. The elasticity for average temperature is 0.536 and significant at the 5% level, which implies that for every 10% increase in temperature the GDP of a country rises by 53.6%. The coefficient for average latitude is 0.499, significant at the 1% level, indicating that if latitude of the country increases by one degree, the GDP rises by 49.9%. Average latitude and temperature are jointly significant at a level of 5% and display a coefficient of -0.008. This implies that if temperature rises by one degree, then with each increase in the latitude by 10%, the GDP of the respective country decreases by 0.8%. On overall the results would imply that countries gain from higher temperatures, that countries in higher latitudes have a much higher GDP compared to countries in lower latitudes, and that the joint effect of latitude and temperature decreases GDP again. The higher the latitude of the country, the more the GDP of the respective country decreases when temperature increases. Because countries gain so much in GDP from being located in higher latitudes, the aggregate effect of the three variables implies that countries in northern latitudes have a higher GDP and countries in lower latitudes have a lower GDP. However, the causal relationship of temperature having positive impacts on GDP in northern latitudes or different impacts on GDP in different latitudes is not proven yet. After all, the estimation might not be optimal since there is a very high correlation between the variables, high standard errors, signs and magnitudes in the four estimations of the model show no clear pattern, and the coefficient of the constant is negative implying there is a region for which the estimations are not valid.

table 4: summary of estimation results with average latitude

	(iv) country- and year fixed effects	
	Coeff.	Std. Error
Constant	-11.280	.760***
Ln(temperature)	.536	.224**
Ln(precipitation)	.013	.012
Latitude	.499	.020***
Latitude* ln(temperature)	**-.008**	**.004****

- Dependent variable: ln(GDP)
- **significant at 5%
- ***significant at 1%

To clarify our results we use an alternative approach to test the research question; we create two sub samples for northern and southern countries. To divide the groups we first set a threshold level at 40[2] degrees latitude, in a second test we set the threshold level at 35[3] degrees. These levels are based on pilot estimates of the impact of temperature on GDP for countries individually. In graphs it can be seen that for countries below 40 and 35 respectively, the correlation is often negative; for countries above these latitudes it is throughout positive. We create dummy variables for northern and southern countries and test the respective interaction effects with average temperature. The results are summarized in table 5, the full estimates can be found in the appendix in table 9. In the first model, with the threshold at 40 degrees, the coefficient for Northern countries is significant and equals 0.122, indicating that for Northern countries the GDP increases by 12.2% when temperature rises by 10%. For southern countries the coefficient is insignificant implying that in southern countries temperature does not influence GDP significantly. When the groups are divided according to the threshold level at 35 degrees the results look similar, although the effect is smaller. The elasticity for temperature and northern countries equals 0.066 and the coefficient for southern countries is insignificant. These results reveal that temperature indeed has a different effect in different latitudes. In the North countries gain more from temperature rises than the average countries, in the south there against, the effect of temperature is insignificant; the examined countries neither gain nor lose from temperature rises.

table 5: summary of estimation results with dummies

			(iv) country- and year fixed effects	
	model	variables	Coeff.	Std. error
1	Northern and	Dummy_north*ln(temperature)	0.122	0.037***
2	Southern countries threshold at 40°	Dummy_south*ln(temperature)	0.099	0.125
3	Northern and	Dummy_north*ln(temperature)	0.066	0.034**
4	Southern countries threshold at 35°	Dummy_south*ln(temperature)	-0.041	0.151

- Dependent variable: ln(GDP)
- **significant at 5%
- ***significant at 1%

Although the average precipitation does not have a significant influence, we also tested the model with interaction effects for dummies for northern and southern countries and average precipitation. It is possible, that precipitation has a significant, diverging effect in

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[2] Southern countries below 40° latitude: Australia, Spain, Greece, Korea, Mexico, Portugal, and Turkey

[3] Southern countries below 35° latitude: Australia, Korea, and Mexico

different latitudes. However, firstly, our estimated models indicated a high variance inflation factor, indicating that the regression is poorly estimated, and secondly, in the full model the coefficient for the interaction effect of latitude and precipitation was equal to zero. This confirms again that precipitation does not have an influence on GDP, also not in different latitudes.

Although the model can be convenient for revealing heterogeneity between countries and years, it does not account for differences in the slope of different countries. It is possible that due to inherent differences in endowments, population, savings, social, economic and political factors the slopes of all countries develop differently. We conduct the F-test for homogeneity of slopes with the Null-hypothesis $\beta = \beta_i$. For the original model with country fixed effects the F-value is 14.233. Thus, the Null-hypothesis is rejected, implying that the slopes of all countries are different. The crucial assumption of homogeneity of slopes is thus not met. Also, for the groups of countries below and above 40 degrees latitude, and above 35 degrees latitude the assumption is not met. Only for the group of countries below 35 degrees latitude homogeneity of slopes is given. The F-value is 3.162, the hypothesis is accepted at the 5% significance level.

VI. Robustness Analysis

To test whether our results are sensitive we test whether the estimates are robust to several specifications. Firstly, it could be argued that extrapolating missing values for the control variables biases the outcomes. It is possible that with the original sample of fewer observations the outcome would be inherently different. To exclude this possibility, the model is re-estimated with the original, non-extrapolated data. All results are summarized in table 6. The full estimations can be found in the appendix in tables 10 to 13. Our initial results are confirmed, since in all models with fewer observations the results are approximately the same (model 1). The average precipitation per year is again insignificant, whereas the average temperature has a positive effect of GDP per capita. An increase in temperature by 10% generates an increase in GDP by 9%. Note, however, that the standard error is larger, and that the result is only significant at the 5% level, implying that the sample with more observations is more appropriate to use.

Secondly, it can frequently be found in literature, that the effects of temperature and precipitation are not linear, but can be described with a quadratic function. An inverted-U relationship for temperature and components of GDP are, for instance, established by Tol (1995), Nordhaus (2006), Mendelsohn et al. (1999) and Rehdanz et al. (2005). It would imply that a rise in temperature and precipitation initially benefits the country, that is, GDP increases, then reaches a certain turning point, and eventually lets GDP decrease again. To test whether an inverted-U relationship is prevalent or describes the relationship better than a linear function, we test the model with a function of the polynomial degree two. Our results do not confirm the findings in literature (model 2). All coefficients, for the linear and the quadratic climate variables are insignificant. Hence, there is no inverted-U relationship of temperature and precipitation and GDP.

In another estimation we test if our results are robust to temperature and precipitation changes. It is possible that these describe the development of GDP more precisely than average temperature and precipitation. Some countries, for instance, might gain from limited climate change, whereas for other countries, that have been exposed to an extreme hot, cold, wet or dry climate in the period before, a change in temperature or precipitation in the current period might be beneficial. The latter has been observed by Maddison et al. (2005). Looking at the estimations in model 3, however, this is not the case. Both temperature change and precipitation change are not significant. Also, the original variables of average temperature and precipitation are not altered as the former remains significant with an elasticity of 0.119 and the latter remains insignificant.

A further objection to the robustness of the results can be an endogeneity problem. One could argue that temperature is dependent on GDP. Possibly, if a high GDP is earned by high industrial activity and this industrial activity triggers high levels of CO2-emissions, then the higher CO2 concentration leads to a higher temperature. Temperature is then indirectly dependent on GDP. If this is the case then our estimations might be biased. To test whether an endogeneity problem exists we conduct IV-estimations where temperature is replaced by the instrumental variable latitude. Latitude has an influence on GDP through temperature, but vice versa it is impossible that GDP has an impact on the geographic characteristic of latitude. Model 4 in table 6 depicts the results of the model using the IV method. Our findings reveal that the reported positive effect of temperature on income is robust for endogeneity and temperature is not dependent on GDP since the coefficients do not differ significantly from the OLS-estimates. The coefficient for latitude is bigger than for temperature, however, in combination with the results of the second research question, this could mean that latitude plays an additional role than only influencing temperature for GDP.

table 6: estimation results alternative specifications

			(iv) country- and year fixed effects	
	Model	variables	Coeff.	Std. error
1	Original data	Ln(temperature)	.090	.044**
		Ln(precipitation)	.012	.013
2	Squared variables	Ln(temperature)	-.084	.143
		Ln(precipitation)	.247	.196
		Ln(temperature) squared	.047	.039
		Ln(precipitation) squared	-.019	.015
3	Temerature and precipitation changes	Ln(temperature)	.119	.038***
		Ln(precipitation)	.025	.016
		Temperature change	-.049	.031
		Precipitation change	-.015	.011
4	IV-estimation	Temperature instrumented by latitude	.476	.015***
		Ln(precipitation)	.007	.012

- Dependent variable: ln(GDP)
- **significant at 5%
- ***significant at 1%

VII. Interpretation and Discussion of Results

The first research question aimed to reveal whether temperature and precipitation, being consequences of climate change, have a significant impact on GDP for 30 OECD countries. The analysis has substantiated that precipitation does not have an overall significant influence on GDP. Technically, precipitation could influence countries at diverse latitudes differently; however, tests have proven that for precipitation effects in different latitudes are insignificant. For temperature, however, we verified that there is a significant positive influence on GDP. The elasticity for the effect of temperature equals 0.084. These results were corroborated when reappraising the effects with different specifications in the robustness analysis. The possibility of an inverted-U relationship between the climate variables and GDP could be excluded. Also, the problem of endogeneity was tested for with IV-estimations, but was proven to be non-existent. In the second research question we established whether these effects could be different for countries in different latitudes. In the first test we showed that both temperature, latitude, and their interaction effect have a significant influence on GDP. Especially latitude is a main influential variable on GDP; the higher the latitude, the higher the GDP. The test, however, was methodological not optimal and did not indicate clearly what the exact effect of temperature in different latitudes is. A further test revealed that the positive effects are stronger for countries in higher latitudes. Testing for northern and southern countries individually, we demonstrate that the positive effect for northern countries is even higher than for all countries taken together, the elasticity equals 0.112. For southern countries the effect is insignificant, implying that the tested southern countries neither benefit nor lose from climate change.

After all, the chief assumption of homogeneity of slopes between different countries is not satisfied. To confirm our results, we estimated our model for all countries individually. Unfortunately no valid results could be obtained, as the coefficients for both temperature and precipitation for individual countries were always insignificant. Possibly, the variability of temperature in the single countries is small, resulting in insignificant results per definition. Also, including trend variables for the temperature in each cross-section did not deliver clear results. In addition to including a general country specific trend, we included trends for the temperature variable in each country to see which countries gain and lose from temperature changes. The estimations for our four models did not deliver results with a clear pattern, as the temperature trends for most countries were insignificant and signs changed.

Alternatively, to make the results more robust and to increase the quality of the research, the countries could be grouped according to similar economic conditions to conduct the analysis for the respective groups. After all, for the group of countries below 35 degrees latitude the homogeneity assumption holds. For their research on the relationship of CO2 emissions and income Dijkgraaf and Vollebergh (2005) pair closely linked countries that "might develop similarly over time – for instance, because they are exposed to common (technology, regulatory, or price) shocks" (Dijkgraaf et al., 2005:18) The classification is based on expert opinions. For many combinations of countries robust results can be obtained; for example, Belgium and the Netherlands display a homogeneous emission-income pattern. For some cases, however, heterogeneity remains present (Dijkgraaf et al., 2005:19).

Our findings can be explained in the following way. That northern countries gain from climate change finds support in literature. Almost all scientists find that northern countries are influenced positively by climate change or that they benefit more than countries in lower latitudes (Mendelsohn et al. (1999), Nordhaus (2006), Maddison et al. (2005), Maddison (2003)). Northern countries are often rich and thus have the necessary means to cope with the effects of climate change (Molle, 2006:190). Also, various sectors might be influenced positively, for instance, crops are larger due to higher temperature and better human health has a positive impact on goods and services production.

Also, the overall positive influence of temperature is in line with these results and the literature. Firstly, we only analyse OECD countries for which a positive impact of climate change on separate sectors has been found by Tol (2002). Secondly, most OECD countries are located in the northern latitudes.

Despite anticipations of a significant impact of precipitation, our findings suggested that precipitation does not have an impact on OECD countries. Possibly, countries have the capabilities to cope with changes and are largely independent of rainfalls. Thus changes in precipitation, whether it is big or small, are not that severe. Another possibility is that the sectors that would be affected by precipitation do not represent a big percentage of the economy. An analysis examining how big the influenced sectors are and how severe the consequences in these sectors are is subject to further analysis.

Finally, it is questionable why we did not find significant impacts of climate change for southern regions. Dell, Jones and Olken (2009) bring forward the theory of adaption. In the long run, regions might adapt to their climate. “Individuals adjust their behaviour to permanent temperature changes, for example, by switching to more appropriate crops, industries, and technologies and by migrating far away from difficult environments altogether” (Dell et al. 2009:201). Hence, the southern countries examined might operate in sectors that are not affected. As in the case for precipitation, an analysis in which sectors the countries examined operate and how they could potentially be affected can give further insight. Nevertheless, our result that southern countries are not significantly affected by climate change contradicts findings in literature that finds southern countries are affected negatively. After all, as we are only analysing OECD countries, we cannot draw conclusions about other southern countries who might indeed have difficulties to cope with the effects of climate change. It is, for instance, possible that the OECD countries analysed have the capacities and a sufficient welfare level to deal with the effects of climate change; other southern countries that are poor might not have these capacities and suffer from more severe consequences. Nordhaus (1994:47f) finds in his study that researchers agree “the response to changing climate will differ between developed and developing countries. […] Developing countries would be more seriously affected than high-income countries.” The impact of climate change on further southern and less developed countries remains subject to further analysis.

From the established fact that temperature elevation has positive overall economic effects on northern countries and that it has no impact on southern countries, one could derive that we should let temperature increase to trigger economic growth. Yet, it would be far-fetched to think that if we increase or decrease the temperature in certain countries, this would lead to economic growth. Literature teaches us differently. After all, there is still an enormous uncertainty with respect to the magnitude, the direction, and the time frame of the effects. And secondly, negative effects on many southern countries found by various researchers are undeniable. Given the information as well as lack of information we currently have, we have to try not to increase temperature further, that is, we drastically have to reduce emissions.

Firstly, we do not know to which extent the effects are positive for some countries, if there is a turning point and when the latter will be reached. Although in our robustness analysis we have not established that the climate change-income relationship can be U-shaped, this has often been proven in literature (Tol (1995), Nordhaus (2006), Mendelsohn et al. (1999) and Rehdanz et al. (2005)). Possibly, there is a turning point and the function is not linear and has an inverted-U shape, however, up to now the consequences are positive. Predictions for the future cannot be made. There is still a lot of uncertainty with respect to the size of the effects, the time frame and if and when there is a turning point from which on the effects are throughout negative. Consequently, even if northern countries currently benefit from climate change, this could change in the near future.

But even more important is the fact that there are numerous countries loosing from climate change, which has been proven in a variety of scientific studies some of which we have introduced in our paper. As mentioned above, our study does not analyse other southern countries than those of the OECD. It is frequently established in literature how southern countries suffer from consequences of climate change. For instance, countries that economically depend on agriculture lose profits when crops are low due to abnormal weather conditions. They lack alternatives and the capacities to deal with those problems. In addition, as they are often dependent on those sectors to a large extent, so that the “relative impacts are more severe in low income countries” (Tol, 2002).

Eventually, the damage done is irreversible. Although there is still uncertainty to a large extent about the causal relationships and consequences of global warming, the strategy of postponing action, waiting to take action until more certainty is gained should not be applied (Tol 1995:367). After all, all damage induced or damage that has not been prevented is irreversible. The more damage done to countries, the harder it will be to re-establish a healthy environment in the end.

Given these arguments, the uncertainty, economic losses for many countries, and the irreversibility of the damage done, the rational policy recommendation found in literature is to reduce CO2 emissions in order to decrease the increase of temperature and thus triggering even more severe effects. The sooner this happens, the less extreme the consequences will be for all countries.

The query how emission reduction can be achieved is a controversial issue in international policy making. Part of the subject matter entails that many northern, rich countries have caused CO2 emissions in the past through high industrial activity. Emissions of greenhouse gases predominantly originate from high-income countries while the negative consequences are felt in low-income countries (Tol, 2009). In recent years industrial activity has been exported to poorer countries. On the one hand, the dispute that arises deals with a large group of countries that want to stop global warming and reduce emissions, and on the other hand it involves the countries that produce a large part of the emissions and profit from it in terms of economic growth. The latter group does often not have a reasonable interest in reducing emissions, as this would either cost a lot of money that could otherwise be invested in further growth or as they would have to lower output and thus cut off profits leading to a deterioration of their growth. After all, the low-income countries produce goods for the export to high-income countries.

Concluding from our research one could argue that it is the northern countries that should make the largest monetary contribution towards reduction of emissions. As the northern countries benefit from climate change and as they are also primarily the countries that caused it, they should have earned enough money by the climate change effect to invest more in preventing further temperature increase in order to prevent further possible harm to the poorer countries. Instead of that poor, high polluting countries cut their emissions per se by producing less or investing in research and technology themselves, especially the northern countries, that gain from the effects of climate change, should make the largest investments in cutting emissions, thus prevent further temperature increases and thus prevent further harm to poorer countries.

In conclusion, to infer valid policy implications, all costs and benefits, economic, social biological and physical aspects on ecosystems and nature have to be taken into consideration and weighted against each other. From existing literature the only rational policy recommendation to give is to take collective actions towards a reduction of CO2 emissions in the present. From our research we can infer that especially the northern countries should make investments in emission reduction and thus prevent poorer countries from further harm, since they gain from the effects of climate change.

Our analysis is bound to several limitations. Firstly, we disregard natural events and catastrophes in the analysis that influence the level of GDP, the temperature, the level of precipitation, and the control variables in certain years. Secondly, we only analyse OECD countries of which not many countries are located in southern latitudes. Hence, we might not have enough data for various southern countries to draw a valid conclusion for the southern countries in general. Furthermore, as already pointed out, we are only analysing OECD countries which are highly developed already, to draw a general conclusion more southern, often less developed countries have to be taken into consideration. Fourthly, there is a restriction to our data. We took the data for temperature and precipitation of only one city per country as the average data per country. The analysis might be more accurate of if either data for the whole country is taken or if the analysis is conducted for smaller, specific regions with the respective latitude, temperature, and precipitation, as, for instance, by Nordhaus (2005). Eventually, our analysis is purely economic. Externalities, such as social costs and benefits of temperature and precipitation changes are disregarded. Mendelsohn et al. (1999:46) point out that it is especially the marginal effects, that is, the social costs of carbon dioxide emissions, of higher temperatures that are expected to be harmful. Tol (2009) stresses that social costs are high, however, uncertain; many studies find different estimates of the level of the latter.

VIII. Conclusion

The phenomenon of climate change and its consequences has stroke numerous countries in the world in recent years. Externalities such as ocean level rising, desertification, changes in rainfall, and storminess affect agriculture, human health, energy use, landscapes, and many other aspects in nature. This again has severe impacts on the economy, in particular on GDP, affecting among others agricultural and industrial productivity and through public health the production of goods and services.

The aim of the research was to advance the understanding of the effects of climate change on GDP. The associated consequences of temperature elevation and changes in precipitation were expected to have a significant influence on output. Furthermore, we expected differences between the impacts of the two variables in northern and southern countries. Our study is the first to examine the aggregate economic effects on GDP resulting from climate change for the 30 OECD countries and with recent data from 1960 to 2008.

For the investigation how temperature and precipitation influence GDP we conducted an ordinary least squares regression analysis. By applying the differences-in-differences estimator, that is by including the fixed effects and accounting for unobserved factors that affect GDP on a national level as well as for time series effects we accounted for the business-as-usual.

Our findings reveal that the overall effect of precipitation on GDP is insignificant whereas the effect of the average temperature per year of a country does have a significant impact on GDP with an elasticity of 0.084. Moreover, we substantiated that among the 30 OECD countries examined northern countries gain more from temperature rises than the average, the elasticity for this group is 0.112, and that for southern countries the effects are insignificant. Our results are robust to several specifications, including models with original, non-extrapolated data, temperature and precipitation changes, and IV-estimations that correct for endogeneity.

That northern countries gain from climate change finds support in literature. Agricultural and industrial production sectors might be influenced positively as, for instance, crops are larger due to higher temperatures, and better human health has a positive impact on goods and services production. That precipitation does not have an impact on GDP can result from the possibility that the changes are not that severe in the countries analysed and thus do not affect the economy. Likewise, it could be that the sectors that would be affected by precipitation do not represent a big component of the economies of the countries examined. Contrary to our anticipations, the impact of climate change on southern countries is insignificant. Possibly, they adapted to their climate very well by operating in sectors that can resist difficult environmental conditions. Furthermore, we are only analysing OECD countries, that by definition have a certain standard of welfare. Therefore, we cannot draw conclusion about other southern countries who might indeed suffer from severe negative consequences.

Existing literature emphasizes the importance to take collective actions towards a reduction of CO2 emissions in the present. It remains undeniable that many southern countries suffer from negative consequences of climate change. Our research suggests financing policies against climate change by the richer, northern countries that gain from the effects of climate change.

In further research several aspects should be focused on. Firstly, the effect of seasonal climate variables should be assessed. Our current model responds to annual temperature and precipitation. Mendelsohn (1999) suggests that future versions of the model should also look at seasonal climate variables. For instance, variables for the hottest and coldest month, and the wettest and driest month of a year could be included or the on average most extreme month is analysed for every year. Secondly, it could be analysed how severe the consequences for different areas are. These could differ, among others, according to the size of the influenced sectors and the number of people living in the area. Impacts would be weighted then according to these measures. Mendelsohn et al. (1999), for instance, examine the impact of climate change with the area and population weighted average temperature and precipitation change. Thirdly, the influence of climate change on GDP could be analysed for more southern located countries. As our analysis only examines OECD countries, no conclusions can be drawn about further southern countries. The impact on all countries is crucial to know in order to make the correct policy choices to reduce CO2 emissions.

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X. Appendix A

A.1 OECD countries

Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States

XI. Appendix B: estimation results

table 7: Model estimations with climate variables and fixed effects

	Model 4: full model with country- and year fixed effect	
	Coeff.	Std. Error
constant	10.713	.198***
Ln(temperature)	**.029**	**.054**
Ln(precipitation)	**-.014**	**.018**
Fixed effect countries	yes	
Fixed effect years	yes	
R square	.966	
Observations n	1344	

- Dependent variable: ln(GDP)
- ***significant at 1%

table 8: Estimations with average latitude and independent variables

	(i) temperature and precipitation		(ii) control variables		(iii) country fixed effect		(iv) country- and year fixed effects	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Constant	-.801	.696	-2.925	.602***	-9.729	.833***	-11.280	.760***
Ln(temperature)	1.926	.246***	.039	.200	.009	.238	.536	.224**
Ln(precipitation)	.480	.042***	.445	.034***	.010	.014	.013	.012
latitude	.115	.011***	.015	.010	.324	.019***	.499	.020***
latitude* ln(temperature)	**-.026**	**.004*****	**.005**	**.004**	**.002**	**.004**	**-.008**	**.004****
GDP growth			-.013	.005***	.003	.001***	.002	.001**
Inflation			-.005	.001***	.000	.000*	.000	.000**
Compensation			-2.778E-14	6.334E-15***	5.382E-15	2.956E-15*	2.669E-14	2.872E-15***
Population density			.000	.000***	.001	.001*	.000	.001
Life expectancy			.104	.006***	.075	.002***	.002	.005
Urban population			.012	.001***	.007	.002***	.005	.002***
Unemployment			-.031	.003***	-.013	.001***	-.010	.001***
Fixed effect countries					yes		yes	
Fixed effect years							yes	
R square	.300		.798		.989		.993	
Observations n	1344		672		672		672	

- Dependent variable: ln(GDP)
- *significant at 10%
- **significant at 5%
- ***significant at 1%

table 9: Estimations with dummy variables for northern and southern countries

	Northern and Southern countries threshold at 40°				Northern and Southern countries threshold at 35°			
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
constant	9.786	.786***	9.645	.485***	10.450	.453***	5.733	1.368***
Dummy_north*ln(temperature)	**.122**	**.037*****			**.066**	**.034****		
Dummy_south*ln(temperature)			**.099**	**.125**			**-.041**	**.151**
Ln(precipitation)	-.004	.017	.005	.013	.003	.014	.026	.016
GDP growth	.001	.002	.004	.001***	.002	.001	.000	.001
Inflation	-.005	.001***	8.823E-5	.000	-.001	.000***	.001	.000*
Compensation	5.394E-14	3.586E-14	1.490E-14	3.901E-15***	9.328E-14	3.325E-14***	7.758E-15	5.100E-15
Population density	.001	.001	.005	.001***	.000	.001	.003	.001**
Life expectancy	.005	.008	-.041	.006***	-.003	.005	.019	.019
Urban population	.002	.003	.016	.002***	.003	.002	.019	.004***
Unemployment	-.011	.001***	-.013	.002***	-.010	.001***	-.022	.003***
Fixed effect countries	yes		yes		yes		yes	
Fixed effect years	yes		yes		yes		yes	
R square	.991		.996		0.992		.999	
Observations n	498		174		600		72	

- Dependent variable: ln(GDP)
- *significant at 10%
- **significant at 5%
- ***significant at 1%

table 10: model with original data

	(i) temperature and precipitation		(ii) control variables		(iii) country fixed effect		(iv) country- and year fixed effects	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Constant	6.827	.297***	-4.973	.774***	4.822	.319***	8.999	.820***
Ln(temperature)	**-.484**	**.047*****	**-.347**	**.050*****	**.089**	**.037****	**.090**	**.044****
Ln(precipitation)	**.581**	**.046*****	**.426**	**.055*****	**.014**	**.013**	**.012**	**.013**
GDP growth			-.007	.008	.001	.001	-.002	.002
Inflation			-.012	.005**	-.005	.001***	-.005	.001***
Compensation			-4.225E-14	.000***	1.140E-14	3.322E-15***	2.164E-14	3.820E-15***
Population density			7.152E-5	.000	.000	.001	-.001	.001*
Life expectancy			.163	.010***	.065	.004***	.014	.010
Urban population			.005	.002***	.005	.003	.004	.003
Unemployment			-.026	.005***	-.017	.001***	-.014	.001***
Fixed effect countries					yes		yes	
Fixed effect years							yes	
R square	.146		.798		.996		.997	
Observations n	1344		315		315		315	

- Dependent variable: ln(GDP)
- *significant at 10%
- **significant at 5%
- ***significant at 1%

table 11: Temperature and precipitation squared

	(i) temperature and precipitation		(ii) control variables		(iii) country fixed effect		(iv) country- and year fixed effects	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
constant	2.696	2.614	-6.953	2.670***	2.840	.731***	9.112	.770***
Ln(temperature)	**-.950**	**.384****	**.559**	**.296***	**.054**	**.161**	**-.084**	**.143**
Ln(precipitation)	**2.040**	**.826****	**1.451**	**.841***	**.300**	**.224**	**.247**	**.196**
Ln(temperature) squared	**.109**	**.086**	**-.190**	**.065*****	**.023**	**.043**	**.047**	**.039**
Ln(precipitation) squared	**-.115**	**.065***	**-.075**	**.066**	**-.023**	**.018**	**-.019**	**.015**
GDP growth			-.015	.005***	.003	.001**	.002	.001*
Inflation			-.004	.001***	.000	.000*	.000	.000**
Compensation			-4.711E-14	.000***	5.548E-15	2.969E-15*	2.627E-14	2.885E-15***
Population density			.000	.000*	.001	.001	2.708E-6	.001
Life expectancy			.130	.006***	.075	.002***	.003	.005
Urban population			.008	.001***	.007	.002***	.005	.002***
Unemployment			-.028	.003***	-.013	.001***	-.010	.001***
Fixed effect countries					yes		yes	
Fixed effect years							yes	
R square	.148		.767		.989		.993	
Observations n	1344		672		672		672	

- Dependent variable: ln(GDP)
- *significant at 10%
- **significant at 5%
- ***significant at 1%

table12: Model with temperature and precipitation changes

	(i) temperature and precipitation		(ii) control variables		(iii) country fixed effect		(iv) country- and year fixed effects	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
constant	6.449	.305***	-3.336	.494***	3.466	.222***	9.499	.447***
Ln(temperature)	**-.490**	**.047*****	**-.311**	**.033*****	**.198**	**.038*****	**.119**	**.038*****
Ln(precipitation)	**.646**	**.048*****	**.589**	**.038*****	**.030**	**.018***	**.025**	**.016**
GDP growth			-.016	.005***	.004	.001***	.002	.001*
Inflation			-.004	.001***	.000	.000*	.000	.000
Compensation			-5.525E-14	.000***	5.789E-15	2.939E-15**	2.590E-14	2.855E-15***
Population density			.000	.000	.001	.001	5.733E-5	.001
Life expectancy			.127	.006***	.074	.002***	.003	.005
Urban population			.008	.001***	.007	.002***	.005	.002***
Unemployment			-.026	.003***	-.013	.001***	-.010	.001***
temperature_change	.370	.191*	.186	.114	-.087	.031***	-.049	.031
precipitation_change	-.299	.067***	-.311	.047***	-.021	.013	-.015	.011
Fixed effect countries					yes		yes	
Fixed effect years							yes	
R square	.164		.779		.989		.993	
Observations n	1319		672		672		672	

- Dependent variable: ln(GDP)
- *significant at 10%
- **significant at 5%
- ***significant at 1

table 13: model with IV-estimations

	(i) temperature and precipitation		(ii) control variables		(iii) country fixed effect		(iv) country- and year fixed effects	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
constant	4.421	.289***	-3.146	.469***	-9.712	.506***	-9.948	.436***
Temperature instrumented by latitude	**.032**	**.002*****	**.017**	**.001*****	**.325**	**.014*****	**.476**	**.015*****
Ln(precipitation)	.549	.042***	.474	.034***	.011	.014	.007	.012
GDP growth			-.014	.005***	.003	.001***	.002	.001*
Inflation			-.005	.001***	.000	.000	.000	.000**
Compensation			-3.797E-14	.000***	4.341E-15	2.962E-15	2.470E-14	2.853E-15***
Population density			.000	.000**	.001	.001*	.000	.001
Life expectancy			.112	.006***	.078	.002***	.005	.005
Urban population			.010	.001***	.007	.002***	.004	.002**
Unemployment			-.029	.003***	-.013	.001***	-.010	.001***
Fixed effect countries					yes		yes	
Fixed effect years							yes	
R square	.255		.792		.989		.992	
Observations n	1352		680		680		680	

- Dependent variable: ln(GDP)
- *significant at 10%
- **significant at 5%
- ***significant at 1%