Weather Conditions and Economic Growth - Is Productivity Hampered by Climate Change?

06.14

Thomas Brenner and Daniel Lee

Philipps Universität Marburg

Impressum:

Working Papers on Innovation and Space
Philipps-Universität Marburg

Herausgeber:

Prof. Dr. Dr. Thomas Brenner
Deutschhausstraße 10
35032 Marburg
E-Mail: thomas.brenner@staff.uni-marburg.de

Erschienen: 2014

Weather Conditions and Economic Growth -

Is Productivity Hampered by Climate Change?

Thomas Brenner[1]

from Economic Geography and Location Research, Philipps-University, Marburg, Germany.

Daniel Lee[2]

from German Meteorological Service, Offenbach, Germany.

Abstract:

Climate change researchers predict a dramatic increase in global average temperature over the next decades. We use past temperature and precipitation fluctuations to investigate whether changes in temperature and precipitation are associated with decreases in economic growth. A GMM panel regression is used to analyze the effects of the average yearly heat index and precipitation on economic growth in 105 countries for the time period 1991-2009.

Keywords: national growth, heat, average yearly temperature, growth effects, panel GMM.

JEL Classifications: O11, O13, E10, C23.

I. Introduction

The last decades were the warmest in the last half millennium (Luterbacher et al. 2004) and climate change researchers predict further increases in global temperatures (IPCC 2013). While climate change and its general impacts are extensively discussed in the literature, economic impacts are mainly studied by theoretical modeling (e.g., Bosetti et al. 2008, Eboli et al. 2009 and Bosello et al. 2012). Empirical studies of the impact of climate on economic growth focuses on the effects of climatologically extreme events (e.g., Skidmore & Toya 2002, Toya & Skidmore 2007, Noy 2009, Aurangzeb & Stengos 2012, Loayza et al. 2012, Strobl 2012 and Fomby et al. 2013).

Regular weather conditions can also impact economic growth. Barrios et al. (2010) find that rainfall is an important determinant for growth in African countries. Such regular weather conditions will change due to climate change. For example, the global average temperature is expected with high confidence to increase by 2°C or more during the current century compared to baseline averages from 1850-1900 (IPCC 2013). Although there is no similar, clear global trend in humidity and precipitation, both of which are highly relevant for a broad range of physiological processes, these variables are expected to change significantly, with varying effects on different regions. We will use yearly fluctuations in heat index, a physiologically relevant measure of perceived temperature based on humidity and temperature, and precipitation in 105 countries to estimate the effects of weather on economic growth. A GMM panel regression is used and different country groups, which are defined according to the economic development and the baseline climates in each country, are studied separately.

We find negative effects of increases in heat index on economic growth, especially in warm, well developed countries. Positive effects are found for increases in precipitation in well developed countries with low average precipitation. The remainder of the paper is structured as follows. The next section provides the theoretical arguments. Section three describes the data and method used. The results are presented and discussed in Section four and Section five concludes.

II. Theoretical background

We consider two main connections between weather and economic growth: The direct effects of weather on the agricultural sector and the effects of weather on the health and well-being of people, which impacts on their working capabilities.

Weather has a direct influence on crops. Especially low rainfall leads to poor harvests or even crop failures. Therefore, low rainfall has a negative impact of economic growth (Barrios et al. 2010). Similarly, in countries with low average temperatures a decrease of temperatures might shorten the plant growth period, also negatively impacting harvests. These effects of weather on crop output should impact economic growth most strongly in countries that depend crucially on the agricultural sector. In these cases, bad weather decreases economic output, which leads to a lower total factor productivity in growth models.

In addition, weather impacts people's health and well-being. Especially hot weather is well-documented to have a negative impact on health as well as the working productivity of people (Kjellstrom et al. 2008). A higher heat index, a physiologically grounded measure of comfort based on relative humidity and temperature, can be expected to lead to decreases in productivity and, hence, economic output. This should especially hold for warm, humid countries. To sum up, weather conditions can be expected to influence the productivity of national economies. We use the standard Cobb-Douglas formulation for modeling changes in economic output (*Y*) in dependence of changes in capital (*C*), human capital (*H*) and labor (*L*), which is inspired by endogenous growth theory (Lucas 1988 and Romer 1990). Since weather is assumed to influence productivity, the weather variables enter the growth equation as usual in the literature (e.g., Wang 2009) as additional terms explaining growth:

$$\Delta\ln\left(\frac{Y_{\mathrm{it}}}{P_{\mathrm{it}}}\right)=\delta\cdot\ln\left(\frac{Y_{\mathrm{it}}}{P_{\mathrm{it}}}\right)+\sum\sigma_j\cdot W_{\mathrm{j,it}}+\alpha\cdot\Delta\ln\left(\frac{C_{\mathrm{it}}}{P_{\mathrm{it}}}\right)+\gamma\cdot\Delta\ln(H_{\mathrm{it}})+\beta\cdot\Delta\ln\left(\frac{L_{\mathrm{it}}}{P_{\mathrm{it}}}\right) \quad (1)$$

with P_{it} denoting the number of inhabitants and Δ standing for the difference between the value at time *t+1* and the value at time *t*. Two variables are used to describe weather: $W_{1,it}$ stands for the mean daily precipitation in each country and year, and $W_{2,it}$ stands for the average heat index in each country and year.

III. Data and method

In total we collected the necessary data on 105 countries, excluding oil exporting countries as usual in the literature (e.g., Bond et al. 2010). Since in the years 1990 and 1991 some East European countries were dissolved and new countries founded, we analyze the time period from 1991 to 2010. The Penn World Table (PWT8.0) provides data that is frequently used in the literature to study economic growth. It contains data on the output-side real GDP at current PPPs (*Y*), the capital stock at current PPPs (*C*), the numbers of persons engaged in each country, which is used as a proxy for the labor input here (*L*), an index that approximates the human capital per person on the basis of years of schooling and returns to education (H), and the population (P) of each country as well as export and import rates, which are used as instruments.

Weather data was taken from the ERA-Interim reanalysis (Berrisford et al. 2009). The original data was remapped onto a regular latitude/longitude grid using bilinear interpolation. Monthly means of daily mean precipitation were computed by summing monthly means of daily convective and large-scale precipitation for each grid cell. Monthly means of the heat index were computed from monthly mean temperature and relative humidity, whereas relative humidity derived from temperature and dewpoint at 2m above ground (Stull 2000):

$$RH = \left(\frac{112-0.1t+t_d}{112+0.9t}\right)^8 \tag{2}$$

whereas RH is the relative humidity, t the temperature and t_d the dewpoint temperature in degrees Celsius. The heat index HI was computed using the methods employed by the National Weather Service (2014), based on (Rothfusz 1990):

$$HI = 1.1t + 0.047 \cdot RH - 10.3 \tag{3a}$$

whereas temperature was measured in degrees Fahrenheit. In cases where the average of the temperature and the computed heat index was above 80°F, the full regression equation was used:

$$HI = -42.379 + 2.04901523 * T + 10.14333127 * RH - .22475541 \cdot T \cdot RH - .00683783 \cdot T^2$$
$$-.05481717 \cdot RH^2 + .00122874 \cdot T^2 \cdot RH + .00085282 \cdot T \cdot RH^2 - .00000199 \cdot T^2 \cdot RH^2$$
(3b)

If the full regression was necessary, it was adjusted if A) the relative humidity was less than 13% and the temperature was between 80 and 112°F or if B) the relative humidity was greater than 85% and the temperature was between 80 and 87°F. In the case of A), the following was subtracted from the computed heat index:

$$\frac{13-RH}{4} * \sqrt{\frac{17-|(T-95)|}{17}} \tag{4}$$

In the case of B), the following was added to the computed heat index:

$$\frac{RH-85}{10} * \frac{87-T}{5} \tag{5}$$

After computing monthly means for heat index and precipitation for each cell, the monthly means were aggregated to yearly means. The yearly means were aggregated spatially to the appropriate countries.

In recent years it has become common in the empirical economic growth literature to use panel GMM regressions, which allow to test for causality with the help of instrument variables (e.g., Hasan & Tucci 2010, Vu et al. 2012 and Museru et al. 2014). We follow this approach and use lagged variables and export and import rates as instruments, as is usual in this literature. Time and country fixed effects are included in the estimations.

IV. Results

Examining the impact of heat index and precipitation fluctuations on economic growth for the whole country sample does not lead to any significant results. Hence, there seems to be no general dependency that holds uniformly for all countries. However, as we argued above, less developed countries, in which the economy depends more on the agricultural sector, should be influenced different by weather than more developed countries. Therefore the sample is divided into those countries with an average GDP per capita ($\phi(Y_{it}/P_{it})$) above and those countries with an average GDP per capital below 6.400 USD.

In addition, increases in heat index should mainly impact those countries with a high average heat index, while low precipitation should mainly influence those countries with low average precipitation. Therefore, we divide the country samples further according to their average heat index and precipitation values. The thresholds for these divisions are chosen such that all samples have approximately the same size. Tables 1 and 2 report the results of the estimations of Equation (1) for each set of countries. The discussion of these results focuses on the impact of heat index and precipitation.

Table 1:

Panel GMM regression results for output growth as dependent variable (Equation (1)) with different sets of countries according to economic output and average heat index (p-values in brackets)

Variable	$\Phi(Y_t/P_t)<6.400$ *AvHeatIndex<70F*	$\Phi(Y_t/P_t)<6.400$ *AvHeatIndex>70F*	$\Phi(Y_t/P_t)>6.400$ *AvHeatIndex<45F*	$\Phi(Y_t/P_t)>6.400$ *AvHeatIndex>45F*
Number of countries	26	27	26	26
$log(Y_{it-1}/P_{it})$	**-.142* (.0130)**	**-.195** (.0090)**	**-.102* (.0172)**	**-.265*** (.0000)**
$\Delta log(C_{it}/P_{it})$	**.465*** (.0007)**	**.474*** (.0000)**	**.311*** (.0000)**	**.461* (.0241)**
$\Delta log(L_{it}/P_{it})$	-.0049 (.9767)	.00013 (.9993)	**1.069*** (.0001)**	.158 (.2781)

$\Delta log(H_{it})$	-.165 (.8954)	**10.51* (.0358)**	-2.27 (.0841)	.298 (.7980)
Precipitation	-9.57 (.4076)	5.75 (.7796)	**28.09** (.0027)**	-4.62 (.7993)
Heat index	-.00052 (.9374)	.0014 (.2395)	.0096 (.1208)	**-.0023* (.0495)**
Number of observations	468	486	468	468

Table 1 does not show any significant results for precipitation and heat index in less developed countries. Hence, our expectation that the more agriculture-dependent, less developed countries are hurt by lower precipitation (as found in Barrios et al. 2010) and high heat index is not confirmed. Possible explanations are either that the less developed countries are too diverse for a consistent impact of weather on economic growth or that the data for these countries is not of sufficient quality for the detection of such relationships.

In the case of more developed countries we obtain a clear picture. Colder countries benefit from higher precipitation. Thus, despite our expectation that the agricultural sector plays no significant role in these countries, their economic growth seems to benefit from better agricultural conditions. As expected, countries with higher average heat indices are hurt significantly by increases in heat index. This confirms the expectation that if the heat index increases in more developed countries with already medium or high heat indices, productivity decreases.

Table 2:

Panel GMM regression results for output growth as dependent variable (Equation (1)) with different sets of countries according to economic output and average precipitation (p-values in brackets)

Variable	*$\Phi(Y_t/P_t)$<6.400* *AvPrecip<.003mm*	*$\Phi(Y_t/P_t)$<6.400* *AvPrecip>.003mm*	*$\Phi(Y_t/P_t)$>6.400* *AvPrecip<.0021mm*	*$\Phi(Y_t/P_t)$>6.400* *AvPrecip>.0021mm*
Number of countries	27	26	26	26
$log(Y_{it-1}/P_{it})$	**-.082** (.0075)**	**-.337*** (.0000)**	**-.148** (.0028)**	**-.197*** (.0000)**
$\Delta log(C_{it}/P_{it})$	**.451*** (.0000)**	.614 (.0588)	**.529*** (.0003)**	**.290* (.0142)**
$\Delta log(L_{it}/P_{it})$	.057 (.7674)	-.092 (.6017)	**.656** (.0015)**	.299 (.0614)
$\Delta log(H_{it})$	-.073 (.9607)	8.58 (.0791)	-1.27 (.2057)	**2.84* (.0366)**

Precipitation	22.83 (.0559)	6.98 (.6899)	**41.97* (.0206)**	-4.84 (.6417)
Heat index	.0048 (.1448)	.0016 (.1573)	-.0023 (.2496)	-.0012 (.3565)
Number of observations	486	468	468	468

If the country sample is divided according to average precipitation (Table 2), the results change slightly for less developed countries. However, still no significant results are obtained for precipitation and temperature. In the case of the more developed countries the results are very similar to those in Table 1. Dividing more developed countries according to average heat index or precipitation leads to very similar sub-samples. However, the results for precipitation and heat index became weaker. This confirms the expectation that high heat indices hurt mainly countries with high average heat indices. In contrast, the expectation that high precipitation is mainly beneficial in countries with low average precipitation is not confirmed. However, the coefficient for precipitation is higher while it is less significant. A final conclusion is not possible.

V. Conclusions

This paper studies whether the variable weather conditions have an impact on economic growth. Significant influences are found for more developed countries: First, countries with low heat index and low precipitation benefit from higher precipitation, a finding that is in line with theoretical predictions that the agricultural sector benefits from increases in precipitation. Second, in countries with higher average heat indices, economic growth decreases with increasing heat index. This is in line with the theoretical prediction that a higher index increases failure rates due to worker illness and reduced worker productivity.

Research on climate change predicts an increase in global temperatures. Our results show that this will have a negative impact on productivity and economic growth in warmer, more developed countries. We do not find significant relationships in less developed countries. One reason might be the quality of the data used. On the one hand, data on less developed countries is essentially more volatile. On the other hand, we use weather information aggregated to the national level and yearly time periods. More detailed regional and monthly data might provide further insights. This would be a valuable endeavor for further studies.

References

Aurangzeb, Z. & Stengos, T. (2012): Disasters on economic growth: A threshold regression approach. *Economics Bulletin* 32 (1): 229-241.

Azman-Saini, W. N. W., Law, S. H. & Ahmad, A. H. (2010): FDI and economic growth: New evidence on the role of financial markets. *Economics Letters* 107 (2): 211-213.

Barrios, S., Bertinelli, L. & Strobl, E. (2010): Trends in rainfall and economic growth in Africa: A neglected cause of the African growth tragedy. *The Review of Economics and Statistics* 92 (2): 350-366.

Berrisford, P., Dee, D., Fielding, K., Fuentes, M., Kallberg, P., Kobayashi, S. & Uppala, S. (2009): The ERA-Interim Archive. *ERA Report Series* 1, European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading.

Bitzer, J. & Kerekes, M. (2008): Does foreign direct investment transfer technology across borders? New evidence. *Economics Letters* 100: 355-358.

Bond, S., Leblebicioglu, A. & Schiantarelli, F. (2010): Capital accumulation and growth: A new look at the empirical evidence. *Journal of Applied Econometrics* 25: 1073-1099.

Bosello, F., Eboli, F. & Pierfederici, R. (2012): Assessing the economic impacts of climate change: An updated CGE point of view. *Nota di lavoro, Fondazione Eni Enrico Mattei: Climate Change and Sustainable Development* 02.2012.

Bosello, F., Roson, R. & Tol, R.S.J. (2006): Economy-wide estimates of the implications of climate change: Human health. *Ecological Economics* 58 (3): 579-591.

Bosetti, V., Carraro, C., Sgobbi, A. & Tavoni, M. (2008): Modelling economic impacts of alternative international climate policy architectures: A quantitative and comparative assessment of architectures for agreement. *Nota di lavoro, Fondazione Eni Enrico Mattei: Sustainable development* 85.2008.

Cerra, V. & Saxena, S. C. (2008): Growth Dynamics: The Myth of Economic Recovery. The American Economic Review 98 (1): 439-457.

Eboli, F., Parrado, R. & Roson, R. (2009): Climate change feedback on economic growth: Explorations with a dynamic general equilibrium model. *Nota di lavoro, Fondazione Eni Enrico Mattei: Sustainable development* 43.2009.

Fomby, T., Ikeda, Y. & Loayza, N.V. (2013): The growth aftermath of natural disasters. *Journal of Applied Econometrics* 28: 412-434.

GDAL (2014): GDAL - Geospatial Data Abstraction Library: Version 1.10.1, Open Source Geospatial Foundation.

Hallegatte, S., Henriet, F. & Corfee-Morlot, J. (2011): The Economics of Climate

Change Impacts and Policy Benefits at City Scale: a Conceptual Framework. *Climatic Change* 104 (1): 51–87.

Hasan, I. & Tucci, C.L. (2010): The innovation-economic growth nexus: Global evidence. Research Policy 39: 1264-1276.

IPCC (2013): Climate Change 2013: The Physical Science Basis. Working Group I contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T., D. Qin, G.K. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kjellstrom, T., Kovats, R.S., Lloyd, S.J., Holt, T. & Tol, R.S.J. (2008): The direct impact of climate change on regional labour productivity. Dublin: ESRI.

Loayza, N.V., Olaberria, E.A., Rigolini, J. & Christiaensen, L. (2012): Natural disasters and growth: Going beyond the averages. World Development 40 (7): 1317-1336.

Lucas, R.E. (1988): On the mechanics of economic development. Journal of Monetary Economics 22: 3-42.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M. & Wanner, H. (2004): European Seasonal and Annual Temperature Variability, Trends, and Extremes Since 1500. Science 303 (5663): 1499-1503.

Museru, M., Toerien, F. & Gossel, S. (2014): The impact of aid and public investment volatility on economic growth in Sub-Saharan Africa. World Development 57: 138-147.

National Weather Service (2014): Heat Index Equation. *Weather Prediction Center, National Oceanic and Atmospheric Administration*.

Neteler, M., Bowman, M.H., Landa, M. & Metz, M. (2012): GRASS GIS: A Multi-Purpose Open Source GIS. *Environmental Modelling & Software* 31 (May): 124-130.

Noy, I. (2009): The macroeconomic consequences of disasters. Journal of Development Economics 88: 221-231.

Romer, P. (1990): Endogenous technological change. Journal of Political Economy 98: 71-102.

Rothfusz, L. (1990): The heat index (or, more than you ever wanted to know about heat index). Technical Attachment SR 90-23. Fort Worth: Scientific Services Division, National Weather Service.

Skidmore, M. & Toya, H. (2002): Do natural disasters promote long-run growth? Economic Inquiry 40 (4): 664-687.

Strobl, E. (2012): The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and

Caribbean regions. Journal of Development Economics 97: 130-141.

Stull, R.B. (2000): *Meteorology for Scientists and Engineers*. Brooks/Cole.

Toya, H. & Skidmore, M. (2007): Economic development and the impacts of natural disasters. Economics Letters 94: 20-25.

Vu, T.B., Hammes, D.L. & Im, E.I. (2012): Vocational or university education? A new look at their effects on economic growth. Economics Letters 117: 426-428.

Wang, M. (2009): Manufacturing FDI and economic growth: evidence from Asian economies. *Applied Economics* 41: 991-1002.