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Does Temperature affect Income?

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Abstract

In this paper, I contribute to the literature on the relationship between temperature and the level of income. I build a panel data set with 198 countries over 36 years. In contrast to the existing literature, I use a Panel Vectorautoregression model and identify temperature shocks with volcanic activity. I find that, in line with theory, volcanic activity creates a significant cooling effect. Then, I present estimated impulse response functions and find that the level of log GDP per capita is reduced by about three percent for more than ten years in response to a 1C increase in temperatures. My results support the existence of a direct effect of temperature on income.

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1 Main

In this paper, I add to the literature exploring the effects of temperature on economic performance.[1] In a cross-section, there is a strong temperature-income gradient (see Figure 1). While recently climate variables have been identified as drivers of this relationship (cf. Horowitz, 2009, Hsiang, 2010, Dell et al., 2012, and Deryugina and Hsiang, 2014) other variables such as institutions (cf. Acemoglu et al., 2001) or other geographical factors (cf. Sachs et al., 2001) could affect this relationship.

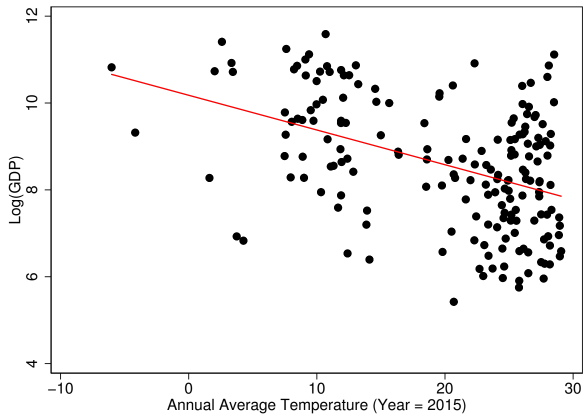

Figure 1: The correlation between temperature and log GDP per capita. Cross-section for 198 countries in 2015. Red line is a log-linear regression with no controls (slope = -0.08, significant at 1% level).

Without a clear idea about the damage function mapping temperature change to economic consequences, researchers need to find different approaches to analyze this link. There are two main streams in this literature. One stream looks at "micro"-level evidence: Niemelä et al. (2002) and Cachon et al. (2012) use plant-level data and show that hot days reduce production. The other "macro" stream of the literature uses country-level data. The studies by Horowitz (2009), Hsiang (2010), Dell et al. (2009, 2012), and Deryugina and Hsiang (2014) all find a negative effects of temperature on income. Heal and Park (2013) and Heal et al. (2017) study the direct effect of temperature on income using a panel of 134 countries from 1950-2006. The underlying idea is derived from human physiology models where temperature stress reduces productivity. They derive a theory predicting an inverted U-shaped response of labor productivity to temperature and find evidence for this theory using panel regressions.[2] Finally, it should also be mentioned that there exists a literature relying on structural, theoretical models simulating the effect of climate variables on the economy. Papers include Bovari et al. (2018) and Rezai et al. (2018), documenting the adverse effects of increases in temperature and the ability of climate policy to mitigate.

[1] See the recent surveys by Dell et al. (2014) and Heal and Park (2016).

[2] I also find evidence for this inverted U-shaped pattern in my dataset (see Table 3 in the appendix).

The novelty of this note is to look at the *dynamic* effects of temperature shocks. I use a Panel Vector autoregressive model (PVAR, for short) to analyze the *direct*, *causal* effect of temperature on income. The benefit of using a PVAR is that it combines a canonical VAR model, where all variables are considered to be endogenous, with a panel model allowing the use of fixed effects. Using fixed effects allows me to control for factors such as institutions or other country-specific effects which is important for this analysis.

In this paper, I build a cross-country panel data set with 198 countries spanning 36 years (1980-2015). In order to identify temperature shocks, I use volcanic activity as an instrumental variable. In my reduced-form results I find that volcanic eruptions, in line with theory, have a cooling effect. Most importantly, I find that there is a causal relationship between temperature and output: the level of output per capita is significantly reduced for about 15 years, with a peak effect of roughly three percent for a $1°C$ increase in temperatures.

My results are generally in line with the literature documenting the relationship between temperature and income levels (cf. Hsiang (2010), Deryugina and Hsiang (2014)). More precisely, they support the findings by Heal and Park (2013) and Heal et al. (2017) showing that temperature shocks affect output levels for about ten years and Dell et al. (2012) showing that output levels and growth rates in poor countries are negatively affected by temperature shocks for roughly ten years. The difference to those two papers is the methodology: both papers use a panel regression set-up while my study uses a Panel Vector autoregression.

2 Empirical Framework

2.1 Methodology

In this note, I use a Panel Vector autoregression model PVARX(p)

$$Y_{i,t} = \mathbf{A}_{i,0} + \sum_{j=1}^{p} \mathbf{A}_{i,j} Y_{i,t-j} + \mathbf{F}_i X_t + u_{i,t}, \tag{1}$$

where $i = 1, \ldots, N$ is the panel unit and $t = 1, \ldots T$ is time (in years). The vector of observables is denoted by $Y_{i,t}$ with dimensionality $(1 \times K)$. Further, $\mathbf{A}_{i,j}$ is a $(K \times K)$ parameter matrix that depends on the panel unit i. Dependent variables linearly depend on exogenous variables, X_t, of dimension $(1 \times r)$ via the coefficients in $\mathbf{F}_i$. Finally, idiosyncratic errors are given by the $(1 \times K)$ vector $u_{i,t}$, where $\mathbb{E}\left(u_{i,t}\right) = 0$ and $\mathbb{E}\left(u'_{i,t} u_{i,t}\right) = \Sigma$.

Before estimating the model, fixed effects are removed by applying a Helmert transformation. Then, the model is estimated using two lags, IV-GMM with five instrument lags, and clustered standard errors at the country level.

I use a four-variable PVARX model with log GDP per capita, trade, unemployment, and temperature.[3] The choice of variables is restricted by data availability and the related literature. We add unemployment in order to control for the link between temperature and labor supply (see Graff Zivin and Neidell (2014)) that could affect GDP. As data for hours worked is not available, this variable is our proxy for the labor adjustment margin. Further,

[3]The results are robust to including the inflation rate and using robust instead of clustered standard errors. In addition, rainfall has an insignificant effect (see Table 3 in the appendix).

we include trade data, because Jones and Olken (2010) show that climate shocks affect exports in poor countries.

I aim to identify the effect of temperature on the level of income, controlling for the effect on trade and unemployment (the labor margin). Estimating such a relationship runs into a fundamental problem: reverse causality (cf. Stips et al., 2016). Income (or production) has an effect on temperature as shown, for example, by Hofmann et al. (2006) and Raupach et al. (2007). Therefore, a standard regression would result in biased results. Therefore, I need an exogenous instrument that only drives temperature but does not affect income. Therefore, my identification strategy is as follows. I use the incidence of volcanic activity.[4] Volcanic eruptions release large amounts of sulfur dioxide (SO_2) and carbon dioxide (CO_2) into the stratosphere but do not affect income. Even if volcanic activity would reduce income or production, the recovery process would counteract the negative effects. There are two possible effects on temperature. First, a cooling effect: sulfur dioxide converts to sulfuric acid which condenses and forms sulfate aerosol increasing reflection of sun radiation. Second, a warming effect: the release of green house gases which increase temperature. My reduced-form estimation results show that volcanic eruptions have a significant cooling effect and, therefore, the instrument does identify temperature shocks.

Finally, at the end of this section, we want to stress that our analysis does not rely on a damage function (Nordhaus, 2008; Dell et al., 2014). In contrast to papers (e.g. Bovari et al., 2018) who rely on damage functions to link climate variables and output, our approach does not rely on such an ad hoc assumption. We see this as an advantage over other studies who make strong structural assumptions about how climate variables affect output. While our approach does not directly allow us to explain *how* temperature affects output, we do not impose any structure on the relationship and allow for a flexible approach; letting the data speak for itself.

2.2 Data

I construct a cross-country panel data set with 198 countries over the time span from 1980 to 2015, which gives me 7128 observations.[5]

Data for income is taken from the World Bank. We measure income by GDP per capita at constant 2010 U.S. Dollar. The other covariates are also taken from the World Bank: trade is measured as percent of GDP and unemployment is the national estimate as percent of the total labor force.

My measure of climate change is the annual average temperature, similar to Horowitz (2009). The historical weather data are taken from the World Bank Climate Change Knowledge Portal. This data set uses gridded temperature data from various weather stations. Finally, our instrument - volcanic activity - is taken from the EM-DAT database. For a volcanic event to be declared as a disaster, at least one of the following criteria must be fulfilled: ten or more people killed, hundred or more people affected, a state of emergency is declared, or a call for international assistance is issued. I do not have any further information on the events. However, more knowledge about the volcanic erruption is econometrically not

[4] I also used the incidence of droughts and the standard deviation of annual average rainfall as instruments. My results are robust to both variations.

[5] A list with all countries can be found in the appendix (Table 1).

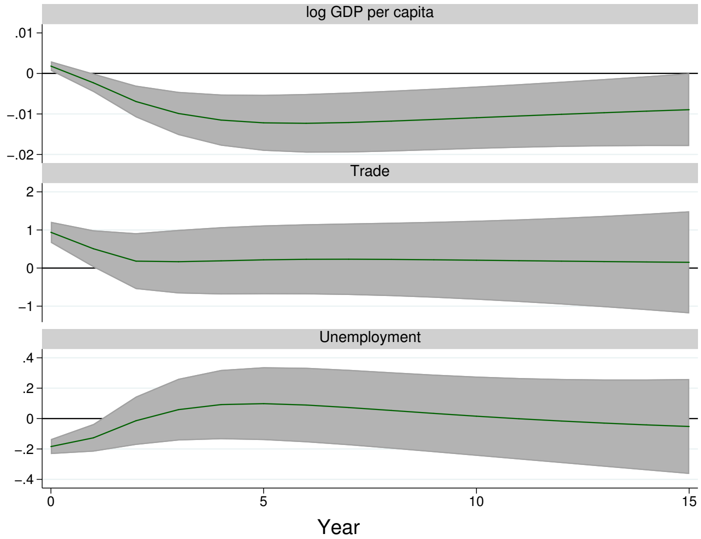

Figure 2: Estimated, identified impulse response functions to a one standard deviation shock to temperature ($0.29°C$). Shaded areas indicate 90% confidence bands.

important. For the estimation strategy to work, I need exogenous variation in temperature over time within a country. Whether, for example, the eruption penetrated a higher or lower layer of the atmosphere is not important for my approach. In fact, it would be preferable for the estimation if the volcanic eruption would not create effects on the global temperature, i.e. penetrating higher levels of the atmosphere, and only create local (within a country) temperature effects, which most volcanic eruptions should do.

Descriptive statistics are presented in Table 2 in the appendix. Annual average temperatures in my sample vary between -8$°C$ and 30$°C$. Volcanic activity varies between zero and four eruptions in a given country within one year. The large variance in temperature and volcanic activity is important for my identification strategy.

3 Results

In this section, I present the estimated impulse response functions for income, trade, and unemployment for an identified temperature shock. Figure 2 presents the estimated, identified impulse response functions of log GDP per capita, trade, and unemployment to a positive, one standard deviation (which equals $0.29°C$) shock in temperature.[6] The shaded areas indicate 90% confidence bands.

Income falls in response to the shock and remains below its steady state for roughly 14 years. This shows the large persistence in the response of income. Then, the peak loss in log GDP per capita is roughly one percent and occurs about five years after the shock. For a $1°C$

[6]The results are robust to including the real interest rate (proxy for monetary policy) and government spending (proxy for fiscal policy).

increase in temperatures this would imply a drop of GDP by three percent. This number is slightly larger compared to the finding by Horowitz (2001) with $1°C$ reducing GDP per capita by 2.4 percent or Dell et al. (2009) with 2 percent. The findings support the results by Heal and Park (2013) showing that the level of output, in response to a temperature shock, falls, stays below trend for some time, but then reverses back once the shock disappears. Also, the results are in line with the findings by Dell et al. (2012) also documenting a reduction in the output level for about ten years but only in poor countries. Both studies employ panel regressions with fixed effects to obtain their results. Our results support the existence of a direct effect of temperature on income. Heal and Park (2013) and Heal et al. (2017) derive a model based on insights from human physiology that links temperature and labor productivity giving rise to an inverted U-shape relationship. I do find strong support for this "micro" pattern in my "macro" data set (see Table 3 in the appendix).

While Dell et al. (2012) also find significant effects on the growth rate of GDP, I do not find such an effect in my PVAR. Running a version of the model using the growth rate of GDP per capita rather than the level, I find no significant effect of temperature on the growth rate of GDP.

I find a reduction in unemployment for about two years. To the best of my knowledge, this is the first paper showing the effect of temperature on unemployment. Graff Zivin and Neidell (2014) find a reduction in hours worked by 14 percent when temperatures are above 30 $°C$ on a day. With falling output, the expectation would be to find an increase in unemployment. However, the effect is small and probably a relict from the negative correlation between the instrument and unemployment in my sample. Further, the response of trade is positive on-impact but is insignificant after about two years. This is a consequence of our definition of trade: when GDP falls, the share of trade in GDP, ceteris paribus, increases. I do not find a significant response of trade volume in a robustness check.

Finally, there are various mechanisms that explain the response and the persistence in the response of GDP (see, for example, Deryugina and Hsiang, 2014). First, there are effects of temperature shocks on agriculture and it will take time to adjust crops or farm management to adapt or mitigate these shocks. Further, people migrate due to temperature changes and this will have transitions costs. Also, temperature has shown to cause conflict, which can negatively affected output for a period of time. Finally, as stated above, labor productivity is negatively affected by temperature leaving the thermal comfort zone. Adjustments, e.g. air conditioning, will take time to be rolled-out on a large scale, i.e. country-wide.

4 Conclusion

In this note I extend the literature on the relationship between temperature and income. I build a large panel data set with 198 countries over 36 years. Then, I use a Panel Vector autoregression model identifying temperature shocks with volcanic activity. I find that volcanic activity creates a significant cooling effect which is in line with theory. Then, I present estimated impulse response functions and find that the level of log GDP per capita is reduced by about one percent for more than ten years. My findings are in line with the results by Dell et al. (2012), Heal and Park (2013), and Heal et al. (2017) showing a persistent effect of temperature shocks on the level of GDP. The results support the existence of a direct effect of temperature on income. The model can be extended to include the effects of disasters on the level or the growth rate of GDP which is left to future research.

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5 Appendix

Afghanistan	Burundi	Estonia	Italy	Micronesia	Romania	Tanzania
Albania	Cambodia	Ethiopia	Jamaica	Moldova	Russia	Thailand
Algeria	Cameroon	Fiji	Japan	Monaco	Rwanda	Togo
American Samoa	Canada	Finland	Jordan	Mongolia	St. Kitts and Nevis	Tonga
Andorra	Cape Verde	France	Kazakhstan	Morocco	St. Lucia	Trinidad and Tobago
Angola	Central African Rep.	French Guiana	Kenya	Mozambique	St. Vincent and the Gr.	Tunisia
Anguilla	Chad	French Polynesia	Kiribati	Myanmar	Samoa	Turkey
Antigua and B.	Chile	Gabon	Korea	Namibia	San Marino	Turkmenistan
Argentina	China	Gambia	Kuwait	Nauru	Sao Tome and Principe	Tuvalu
Armenia	Colombia	Georgia	Kyrgyzstan	Nepal	Saudi Arabia	Uganda
Australia	Comoros	Germany	Laos	Netherlands	Senegal	Ukraine
Austria	Congo	Ghana	Latvia	New Caledonia	Serbia	United Arab Emirates
Azerbaijan	Costa Rica	Greece	Lebanon	New Zealand	Seychelles	United Kingdom
Bahamas	Cote d'Ivoire	Grenada	Lesotho	Nicaragua	Singapore	USA
Bahrain	Croatia	Guatemala	Liberia	Niger	Slovakia	Uruguay
Bangladesh	Cuba	Guinea	Libya	Nigeria	Slovenia	Uzbekistan
Barbados	Cyprus	Guinea-Bissau	Liechtenstein	Norway	Solomon Islands	Vanuatu
Belarus	Czech Republic	Guyana	Lithuania	Oman	Somalia	Venezuela
Belgium	DPR Korea	Haiti	Luxembourg	Pakistan	South Africa	Viet Nam
Belize	DR Congo	Honduras	Macedonia	Palau	Spain	Western Sahara
Benin	Denmark	Hong Kong	Madagascar	Palestine	Sri Lanka	Yemen
Bhutan	Djibouti	Hungary	Malawi	Panama	Sudan	Zambia
Bolivia	Dominica	Iceland	Malaysia	Papua New Guinea	Suriname	Zimbabwe
Bosnia and Herz.	Dominican Rep.	India	Maldives	Paraguay	Swaziland	
Botswana	Ecuador	Indonesia	Mali	Peru	Sweden	
Brazil	Egypt	Iran	Malta	Philippines	Switzerland	
Brunei	El Salvador	Iraq	Mauritania	Poland	Syria	
Bulgaria	Equatorial Guinea	Ireland	Mauritius	Portugal	Taiwan	
Burkina Faso	Eritrea	Israel	Mexico	Qatar	Tajikistan	

Table 1: Country list.

Variable	Obs	Mean	Std. Dev.	Min	Max
Temperature	7020	19.34	8.21	-7.93	29.75
ln GDP	6062	8.26	1.51	4.75	11.89
Inflation	6181	41.86	511.84	-31.9	26765.86
Unemployment	3089	8.85	6.08	0	59.5
Trade	5902	84.03	52.78	0.02	531.74
Droughts	6822	0.08	0.28	0	3
Rain STD	6840	62.57	45.72	$3.71e^{-15}$	314.78
Volcano	6822	0.02	0.19	0	4

Table 2: Summary statistics.

Variable	1	2	3	4
Temperature	0.05***	0.04***	0.03***	−0.01
	(0.01)	(0.01)	(0.01)	(0.04)
Temperature^2	−0.002***	−0.001***	−0.001**	−0.00005
	(0.0003)	(0.0003)	(0.0004)	(0.0008)
Rainfall		0.0001		
		(0.0002)		
Obs.	6005	5840	3231	2375
R^2_{adj}	0.98	0.98	0.95	0.9
Countries	All	All	High-Income	Low-Income

Table 3: Regression results. Dependent variable: log GDP per capita. Robust standard errors shown in parentheses. Regression with high-income countries uses high- and upper-middle income countries for the low-income, we use low- and lower-middle income countries. The regression uses year and country fixed effects. Constant not shown. Significance levels: ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.10$.