Arbejdspapir 70:
Climate change and institutional change – what is the relative importance for economic performance

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A growing empirical literature attempts to assess the effect of climate and institutional quality (measured by e.g. economic freedom) on economic growth, both being important fundamental growth conditions. So far, these conditions have been studied apart, even if they from a theoretical point of view are non-exclusive and could both be important. This study investigates their interaction and relative importance, using dynamic panel models. Both global warming and declining institutional quality affect growth adversely. A permanent negative shock of one unit to institutional quality (on a 0-10 scale) is associated with a 10.4 per cent lower long run GDP. In our preferred model the adverse growth effect of global warming is significant and large compared to the literature, implying a 3.4 per cent drop in global GDP from a one-degree Celsius temperature rise. The effect is quadratic; for 79 per cent of the World the adverse effect of a temperature rise of one degree would be dwarfed by the effect on GDP of a one-point fall in institutional quality. Our study suggests that policies to reduce global warming should not be at the expense of policies to enhance institutional quality, which are more important for long time growth.

JEL: E23, Q54, Q56

Key Words: Institutional quality, temperature, economic wealth, economic freedom, global warming

Data and programming available at www.cepos.dk/documentation

Introduction

Which factors determine the wealth of nations?

In modern economic and political theory, three root causes or “environmental” factors stand out: Institutions, geography, and culture.

Fundamental or environmental factors would not be fundamental if easily changeable and subject to day-to-day political decision making. However, some are changeable none-the-less and subject to deliberate policies. Two of them have been on the political agendas for some time, one institutional and one geographical. The first is the question of economic institutions. On a global scale, institutional change has been substantial in many cases in the post-war era, ranging from regime changes in some countries to piecemeal economic reforms in most. Substantial institutional international variation subsists, however. The other is the question of climate change. While no country can change its climate on its own, several international attempts have been made to accomplish a concerted action against global climate change. Most countries are committed to undertake policies to reduce greenhouse gas (GHG) emissions widely believed to be an important driver of climate change.

Climate change has been dubbed "the greatest market failure the world has seen" (Stern 2007). Similarly, poor institutional quality might be seen as the major government failure, underlying other government failures.

While the economic and social impact of both climate change and institutional factor have been studied in separate literatures, there has been little overlap, even if both are potentially important "environmental factors". Indeed, each strand have found little relevance of the other.

The present study contributes in the following way. First, we bridge the gap in the previous econometric literature by examining the combined effect on growth of institutional quality and climate change, identifying the relative importance and robustness of both. We show that it is inappropriate to exclude either factor as has been the case in previous studies. Second, we devise a method to estimate long term effects of climate change, using GDP per capita levels rather than growth rates as the dependent variable. Previous "top down" studies have in effect only been able to derive shorter term effects, which are less relevant to climate policy issues. Furthermore, they raise concerns about lack of robustness as well as omitted variable bias. Third, we contribute to the growing body of estimates of the impact of climate change. Such estimates used e.g. by the IPCC, are paramount to advice on climate change policies. Fourth, we introduce an instrument variable to infer a causality leading from institutions to growth, which is otherwise difficult to establish in panel regressions. Finally, we point to important policy implications. Increased focus on climate change should not be at the expense of economic institutions and institutional reform, since in most countries deteriorating institutional quality could have at least as negative economic impact as global warming. E.g. an increased emphasis on climate change in development aid at the expense of institutional improvement (such as imbodied in the Washington Consensus) could have adverse net effects. Institutional change and climate policy could be tied to avoid net negative growth effects and could provide basis for economic policy coalitions.

We organize the paper as follows: We begin by introducing the previous literature. Next, we introduce our approach and main findings. We then provide an extended presentation of the theoretical motivation for our estimation equations and motivate the choice of data. In the following sections we conduct estimations. First, we show that temperature changes do not drive recent changes in institutions, and the latter should not be excluded from models explaining growth by temperature changes. Second, we estimate and discuss a number of models, preferring a model with heterogenous effect of temperature and constant semi-elasticity of institutions. Third, we deal with important robustness and causality issues. Finally, we conclude and point to policy conclusions.

A brief overview of institutions, climate change and economic growth

The link between GHG emissions and climate change is being studied extensively in a number of natural sciences. The social and economic impact of climate change is, however, primarily an economic question: What are the consequences in terms of wealth and economic welfare of a rise in temperature? Assessing the economic impact of climate change is usually done by an integrated assessment model (IAM). There are three major models, DICE, FUND and RICE. In these models, a damage function quantifies the economic effects of climate changes (cf. e.g Nordhaus 2013). In all three models, the damage function is quadratic in the temperature change since pre-industrial revolution levels (temperature itself being a function of GHG concentration in the global atmosphere). At the same time, they also model the costs of reducing GHG emissions, making e.g. energy more costly. From IAMs it is possible to derive optimal intertemporal trajectories for global heating, minimizing total cost from both heating and abatement.

Damages in IAMs are mostly estimated from a bottom-up approach. The bottom-up approach consists of estimates of costs in specific areas (e.g. mortality and crop failure) from warming as well as from mitigating such consequences (e.g. avoiding flooding by erecting dykes). The methodology resembles that of cost-benefit-analysis of projects, linking, however, a vast number of projects together. The top-down approach, on the other hand, is based on the overall correlation between variation in temperature and output. Such a correlation internationally is well-known, but also known to be mostly spurious, (Acemoglu, Johnson, and Robinson 2001; Rodrik, Subramanian, and Trebbi 2004). Many low-income countries are situated in areas with a warm climate, while some wealthy countries, such as Canada and Norway, face relative cold climates.

Two recent studies have tried to estimate the top-down effect of temperature on GDP per capita directly, using comprehensive international data.

A pioneering contribution to the top down-literature was Dell, Jones, and Olken (2012). Based on temperature and precipitation measurement at different points around the globe from 1950 to 2003, they constructed a population weighed country-specific data set, which also includes GDP per capita growth rates. In an econometric analysis, they find that short term shocks to the temperature were associated with a substantial adverse effect on economic growth rates in poor countries (defined by having less than global mean GDP per capita the first year they entered the sample), though not in richer countries. A one-degree Celsius increase in temperature in a given year was associated with a 1.4 percentage point reduction in economic growth the same year for poor countries. They also reported some indications that temporary temperature shocks affect growth rates persistently, which implies that temporary shocks to temperature have permanent level effects for poor countries. The long-term effect is essential since especially an un-foreseen short term impact from temperature shocks might deviate in impact from that of a permanent rise in temperature; for example, Zivin, Hsiang, and Neidell (2015) found long term adverse effects on human capital formation from warming to be much smaller than short term ones.

Burke, Hsiang, and Miguel (2015) found a negative non-linear effect of temperatures on GDP per capita growth rates for all countries, consistent with the non-linearity of the damage functions in AIMs (which, however, links temperature to GDP levels).

The role of institutions in promoting economic growth and prosperity is a question of considerable width and depth in economic science, going back at least to Adam Smith (Smith 2002[1776]). Some recent theoretical contributions include North (1990), Hurwicz (1996), Brennan and Buchanan (2008), Olson (2008), Hayek (1981) and Acemoglu, Johnson, and Robinson (2004) to mention but a few. An important contribution to the empirical literature on economic growth was Barro (1989), who inspired a substantial number of panel data studies including, among other variables, institutional features of countries, tracking their importance for growth.

One difficulty determining whether institutional quality determines a country's income level in the long run is the potential reversed causality. Is a country rich because of its high-quality institutions or did the country invest in high-quality institutions because it is rich? In cross-section settings, Acemoglu, Johnson, and Robinson (2001) and Rodrik, Subramanian, and Trebbi (2004) overcame the issue of the reverse causality by using (log) settler mortality rates as an instrument for the current institutional quality in former European colonies[1]. The underlying reasoning is that countries with high mortality rates were less settled and less were invested in their constitutional framework. In this setting, they show that the relationship between temperature and GDP per capita is spurious in the sense that only institutional quality matters for a country's long-run income level.

The empirical growth literature based on comprehensive international panel data is still limited with regard to both institutions and temperature. Two of most prominent studies, (Acemoglu, Johnson, and Robinson 2012; Dell, Jones, and Olken 2014a), have each rejected the relevance of the factor claimed by the other side to be of sole importance. That warrants a closer inspection. Furthermore, the literature on temperature give rise to concerns regarding especially robustness and long-term effects on growth. We explore both types of problems and suggest a new approach.

Our approach and our main findings

In our study, we combine the cross-sectional institutional approach, with the "top-down approach" in climate studies. Hence, we perform panel-regressions, including both institutional quality and weather variables.

In our empirical models, the weather data is from Dell, Jones, and Olken (2012) and the data on economic activity is chained PPP GDP per capita from the Penn World Tables.

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[1] There has however been some concern with Acemoglu, Johnson, and Robinson (2001)'s settler mortality data. Albouy (2012) and Fails and Krieckhaus (2010) argue that the causal relationship between economic growth and institutional quality is driven by "Neo-Europe" (i.e. Canada, USA, Australia and New Zealand) and measurement errors in log settler mortality. However, Acemoglu, Johnson, and Robinson (2012) argued that when one does not exclude more than half of the previous colonies (as Albouy (2012) does), the results from Acemoglu, Johnson, and Robinson (2001) are robust to measurement errors and the exclusion of "Neo Europe".

Measuring institutions is not straight forward. Many constitutional, economic, legal and political features might count as institutional. Attempts have been made to find measures, which collapses the potential many-dimensional institutional qualities of countries into one or a few overall indicators. As the measure of institutional quality, we use the widely used Economic Freedom Index, (Gwartney, Lawson, and Hall 2017). One advantage of this index is that it captures both "deep", rather fixed institutional factors, such as the prevalence of the rule of law, as well as more transient factors such as the tax system and the outcome of monetary policy arrangements. We are looking at institutions, which might be subject to change also in the shorter run due to political decisions, while not being simply current economic policy.

We follow the traditions of the institutional approach and use log settler mortality for former colonies as an instrument to give the effects of institutional quality a causal interpretation. To the best of our knowledge, we are the first to use this instrument in a panel data set.

Another contribution is an explicit focus of the stability of the estimated models. In our theory section, we will argue that it is not clear if the estimated models in Dell, Jones, and Olken (2012) and Burke, Hsiang, and Miguel (2015) are stable in the sense that the fitted growth rates do not trend. The instability problem arises from the fact that the temperature is an explanatory variable which is trending and none of the studies cited test for stability of the estimated models.

An additional limitation of the previous panel growth models is that they do not identify the long-run economic effects of a permanent shock to the weather variables, which is of particular interest[2]. Instead, the panel growth regressions generally only identify the short run economic effects of transitory shocks to the weather variables[3].

Given these difficulties with panel growth regressions, we instead perform panel regressions with log PPP GDP capita as the dependent variable (rather than growth rates as in previous studies), and we allow for persistence by including lagged dependent variables. In this setting, we can use panel unit roots tests to test if log GDP per capita is conditional stationary, which is required for us to compute the long-run effects of a permanent shock to one of the covariates (Acemoglu et al. 2019).

[2] Dell, Jones, and Olken (2014) argued that there are some specific case studies which provide information on the long effects of weather variables, but this is not what is done in the panel growth regressions.

[3] Dell, Jones, and Olken (2012) show that their estimates of the effects of short run weather fluctuations are in line with the medium effects of weather fluctuations, but still they do not provide estimates of the long-run economic effects of permanent shocks to the weather variables.

For the model to be as parsimonious as possible, we will choose the smallest set of deterministics necessary for the dependent variable to be conditional stationary.

A potential problem with “dynamic level” regressions, as compared with “growth rate” regressions, is that it is more challenging to use instruments to offer causal inference for the effect of institutional quality on growth. The reason is that in the first stage of a two stage least squares regression, we include lagged log GDP per capita, which has a clear trend for most countries; this is an issue since the Economic Freedom Index is a bounded variable. Hence, it is somewhat easier to make causal inference in the growth regression model, which is why we choose such a model in this context.

Our main findings are that institutional quality has a substantial positive effect on GDP per capita and that there is a quadratic relationship between temperature and log GDP per capita; Specifically, a permanent one unit increase in the Economic Freedom Index is associated with 10.4 pct. higher GDP per capita. This finding is quite robust. We find suggestive evidence that the relationship between GDP per capita and the Economic Freedom Index has a causal interpretation. Our results suggest that temperature affects GDP per capita through channels which are not linked directly to the institutional quality. These channels could include the effects of warming on agriculture, investments and industrial production (Dell, Jones, and Olken 2012).

Methodological approach and data

Dell, Jones, and Olken (2012) and Burke, Hsiang, and Miguel (2015) estimate panel models with the growth rate of GDP per capita as the dependent variable and the weather variables (i.e. temperature and precipitation) as covariates and some deterministics. However, since temperatures have increased in the period of interest, (Dell, Jones, and Olken 2012), it not apparent if the fitted growth rates are trending, which would be at odds with the empirical evidence. If the fitted growth rates are trending, the empirical model is unstable. Importantly, the stability of the estimated models depends on the deterministic part of the model which Dell, Jones, and Olken (2012) and Burke, Hsiang, and Miguel (2015) do not handle the same way. Hence, it is appropriate to test for the stability of the estimated models formally[4]. An evident approach is to follow Acemoglu et al. (2019) and include lagged dependent variables in the empirical models and use panel unit root test to check for conditional stationary of the dependent variable. However, in the technical appendix, Dell, Jones, and Olken (2012) argued that due to the low serial correlation

[4] An informal check of the stability of the estimated models could be to plot of the average fitted growth rate over time; in such a figure the fitted growth rates should not be trending.

in the growth rates it is not appropriate to include lagged dependent variable to panel growth regressions.

An alternative to the potential problematic growth regressions is to use log GDP per capita as the dependent variable. There are at least two advantages of using log GDP per capita as the dependent variable instead of the GDP per capita growth rate. First, it is not at odds with the empirical evidence if the fitted values of log GDP per capita are trending. Second, since the serial correlation in log GDP per capita is quite strong, it is not a problem to included lagged GDP per capita as explanatory variables in the panel regressions. Third, we can estimate the long run marginal effects of permanent shocks to any of the covariates. In panel regression models, it is only possible to identity short to medium effects of transitory shocks to the covariates. Finally, it is possible to use panel unit root tests to formally check for conditional stationarity, since it is not problematic to include lagged dependent variable. An evident approach is to consider different kinds of deterministics and choose the simplest form of deterministics, which provides a conditional stationary dependent variable.

Since models with log GDP per capita are more attractive than models with the growth rate of GDP per capita, we will provide theoretical motivation for semi log-linear estimations equations.

Inspired by Dell, Jones, and Olken (2012), we assume that the production function has the following form:

$$Y_{i,t} = A_{i,t}e^{\sum_{j=0}^{q}(\beta_j T_{i,t-j}+\alpha_j E_{i,t-j}+\sigma_j P_{i,t-j})}L_{i,t}$$

Where Y denotes GDP, T is temperature, E is institutional quality, P is precipitation, L is labour and $A_{it}\, e^{\sum_{j=0}^{q}(\beta_j T_{i,t-j}+\alpha_j E_{i,t-j}+\sigma_j P_{i,t-j})}$ is total factor productivity and we assume that:

$$A_{it} = f\left(\frac{Y_{i,t-1}}{L_{i,t-1}}, \dots, \frac{Y_{i,t-p}}{L_{i,t-p}}\right)$$

We assume a log-linear form of f, i.e.

$$log(A_{it}) = \sum_{j=1}^{p} \gamma_j log\left(\frac{Y_{i,t-j}}{L_{i,t-j}}\right)$$

Which leads to the following estimation equation:

$$log\left(\frac{Y_{it}}{L_{it}}\right) = \rho d_{it} + \sum_{j=1}^{p} \gamma_j log\left(\frac{Y_{i,t-j}}{L_{i,t-j}}\right) + \sum_{j=0}^{q}(\beta_j T_{i,t-j} + \alpha_j E_{i,t-j} + \sigma_j P_{i,t-j}) + c_i + u_{it} \quad (1)$$

where d_{it} denotes the deterministics. In this setting we can obtain a direct estimate of the approximate long-run semi-elasticity of GDP per capita of with respect our independent variables as follows (we report on temperature to illustrate):

$$\varepsilon_{\left(\frac{Y}{L}\right),T} = \frac{\sum_{J=0}^{q} \widehat{\beta_J}}{1 - \sum_{j=1}^{p} \widehat{\gamma_J}} \quad (2)$$

provided GDP per capita is stationary conditional on the variables in (1). To get standard errors of (2), one can use the delta method or the bootstrap. In our applications, we will use the delta method to get standard errors of (2).

We can test if log GDP per capita has a (conditional) unit root using the test developed in Levin, Lin, and James Chu (2002).

Finally, if the model is conditionally stationary, it is consistent with conditional convergence, and we can obtain a direct estimate of the rate of convergence as $1 - \sum_{j=1}^{p} \widehat{\gamma_J}$.

Data on population-weighted temperature and precipitation on a country-level are from Dell, Jones, and Olken (2012). Since measuring points do not coincide with countries, original data has been transformed to national levels using population weights from 1990. The climate data runs from 1951-2003. We note that Dell, Jones, and Olken (2012) only include countries for which they have at least 20 years of data in their regressions. To make our results comparable to their, we include the exact same temperature and precipitation data as they did. The sample thus includes all countries on a global scale, except for cases in which special circumstances have resulted in insufficient data.

National account data are from Penn World Table 9.1, (Feenstra, Inklaar, and Timmer 2015). Specifically, we use output GDP per capita instead of expenditure GDP since the former is closer to a production measure. The Penn World Table provides chained PPP GDP per capita from 1950 to 2017. Chained PPP GDP per capita is the relevant measure since we want to compare GDP per capita across time and countries.

As our measure of institutional quality, we use the Economic Freedom Index from *Economic Freedom of the World* (Gwartney, Lawson, and Hall 2017) from the Fraser Institute et al., running from 1970[5] to the present. It has been widely used in the recent literature as an institutional measure. And important advantage of the index is the time variant variation for individual countries even in the shorter term. Other measures such as scores by Transparency International (corruption)

[5] Note, that this index is constant in the years 1970-1974, 1975-1979, 1980-1984,1985-1989,1990-1994, 1995-1999.

and Freedom House (political freedom) change very little in the shorter term[6]. The Economic Freedom Index is an average of five sub-indices for 1) the size of government: expenditures, taxes and enterprises; 2) legal structure and security of property rights 3) access to sound money; 4) freedom to exchange with foreigners; 5) regulation of business, credit and labor. Each sub-index consists of a host of indicators. Hence, the Economic Freedom Index provides an aggregate measure of the extent to which is a country is characterized as a market economy in which trade is voluntary, competition is free, and property rights are protected. A value of zero means that a country has "no economic freedom" and a value of ten means that the country has "full economic freedom".

In our econometric models, we will use data from 1970 to 2003, since 1970 is the first year that we have data on the Economic Freedom Index, and consistent economic relevant temperature data are not available beyond 2003[7]. We note that the panel is unbalanced since we do not have data for all countries in the early part of the sample.

Table 1 summarizes some descriptive statistics for weather variables and institutional quality.

Table 1 - Summary statistics

	Temperature	Precipitation	Economic Freedom Index	Log settler mortality
Mean	19.38	11.85	5.71	4.68
Standard deviation				
- Overall	7.14	7.38	1.36	1.32
- Between	7.13	7.09	1.08	1.32
- Within	0.53	2.13	0.80	0.00

[6] In the present study, indicators from both institutions have been tried as a substitute for the EFI; the with-country variation, however, is to small.

[7] Dell, Jones, and Olken (2012) similarly does not include data beyond 2003.

We see that for all variables the between-variation is substantial. Comparably, the within-variation is quite low for all the variables; this is especially true for temperature. Finally, log settler mortality is a time-invariant variable with no within-variation.

Figure 1-3 demonstrates the between-countries relationships between the Economic Freedom Index, temperature, precipitation and log GDP per capita. Figure 4 depicts the between-countries relationship for temperature and the Economic Freedom Index.

Figure 1. EFI against log GDP per capita in 2003

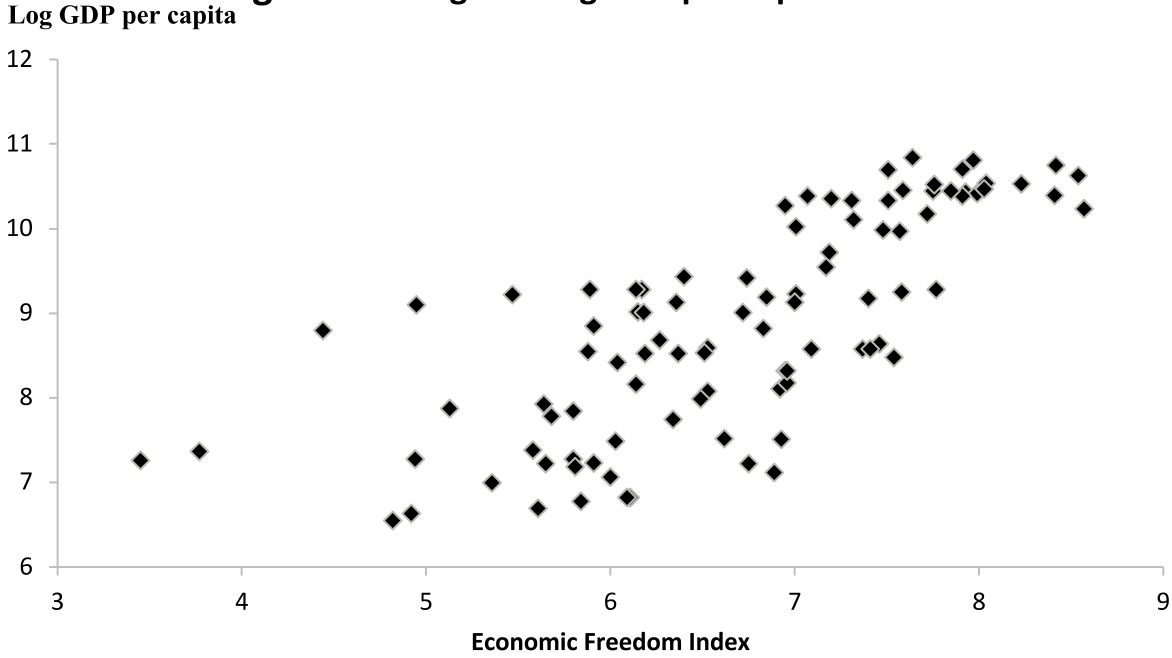
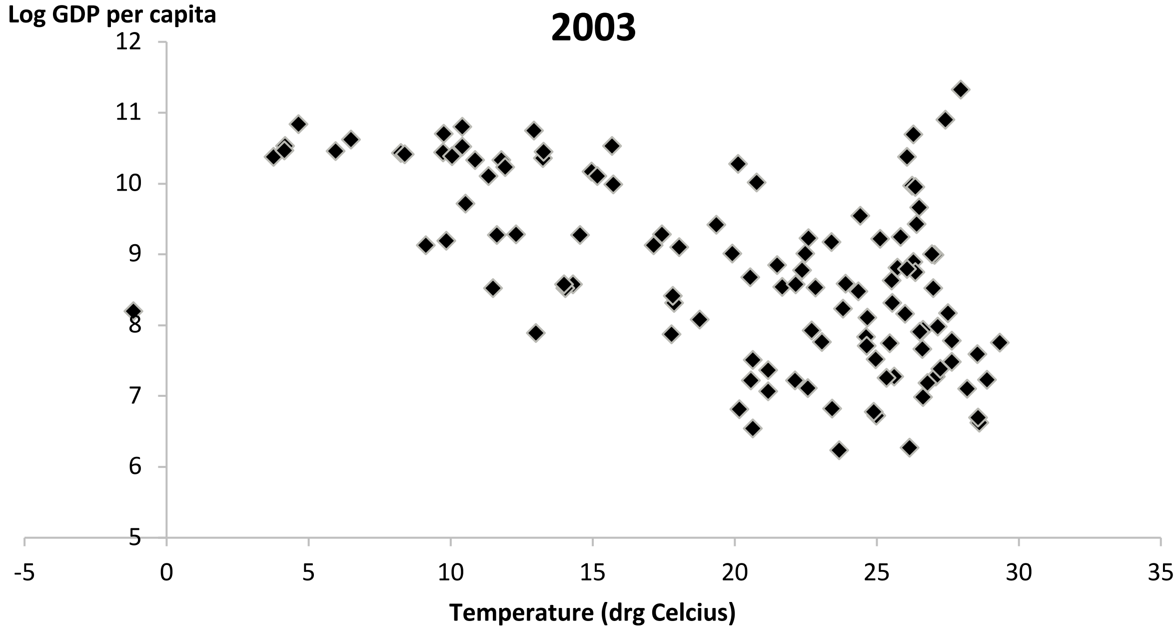
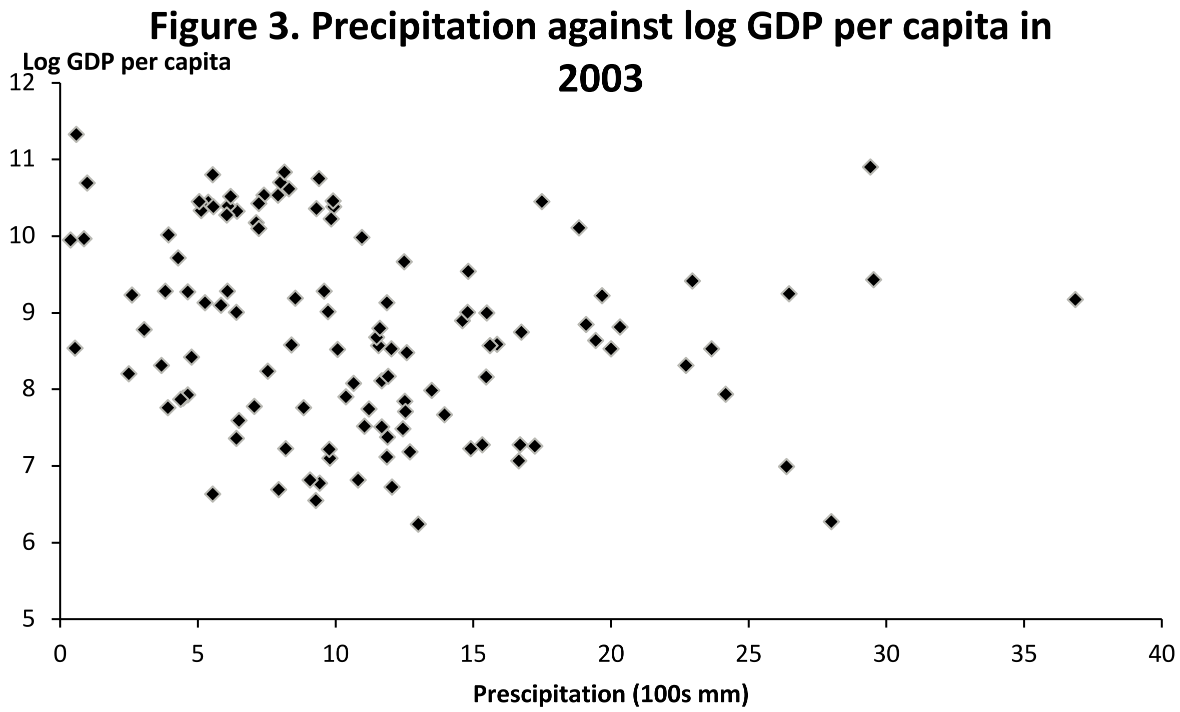
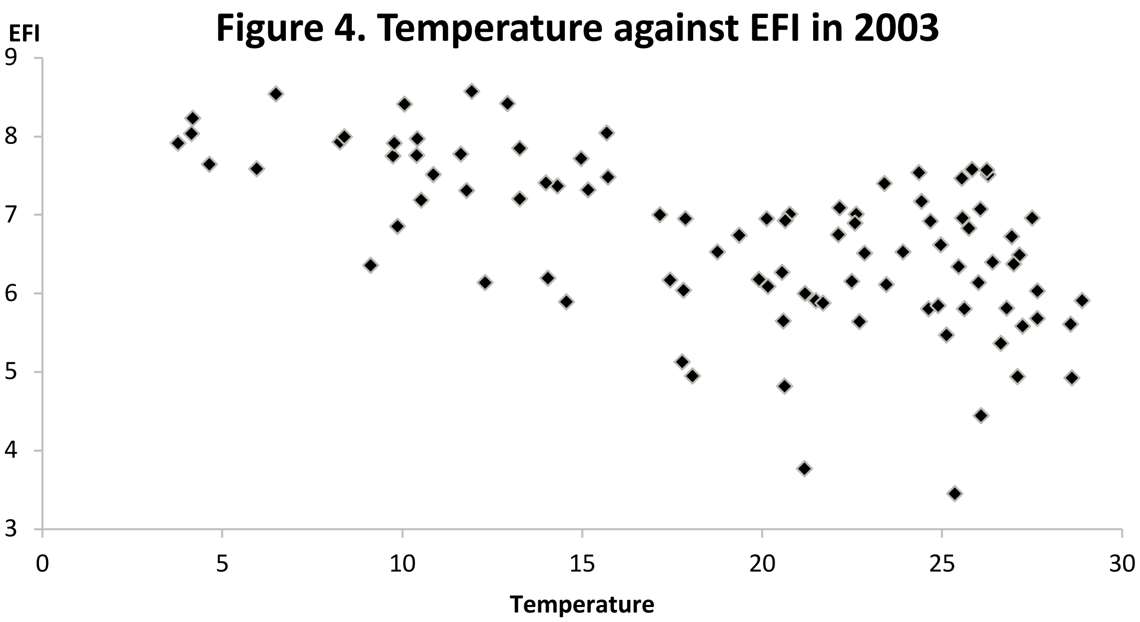


Figure 2. Temperature against log GDP per capita in 2003







As figure 1 and 2 indicate, there is a negative correlation between temperature and GDP per capita and a positive correlation between GDP per capita and Economic Freedom Index, while a correlation between GDP and precipitation hardly exists (figure 3). Figure 4 indicates a clear tendency for colder countries to have higher quality institutions.

Does temperature cause institutional quality?

Dell, Jones, and Olken (2012) chose to exclude institutional explaining variables, arguing (in some detail in Dell, Jones, and Olken 2014) that climate is likely to be a root cause of institutions, in which case it is inappropriate to include both institutional quality and weather/climate variables in the same regression.

Indeed, in some very fundamental sense, Acemoglu, Johnson, and Robinson (2001) and Rodrik, Subramanian, and Trebbi (2004) did not show that climate was not a root cause of institutional quality, since the climate, of course, did play an important role in settler mortality (mainly due to malaria and other tropical diseases). However, even if the climate were a root cause of the institutional framework adopted during colonization, and even if there might be a high degree of path dependency behind present-day institutions, it does not follow that more recent and gradual changes in climate will also lead to similar changes in institutional quality.

Thus, an important question is if current weather fluctuations can be expected to affect institutional quality today. In this section, we test if that is indeed the case.

The basic idea is that if weather variables cause institutional quality, then there necessarily must be a partial correlation to test for empirically. To determine if there is a partial correlation between weather variables and institutional quality, we run a random effect model[8] for the Economic Freedom Index using temperature and precipitation as explanatory variables. We follow Dell, Jones, and Olken (2012) and assume that the marginal effects of temperature can be different for rich and poor countries[9]. In table 2, we report the results.

Model 1 in table 2 does imply a strong negative partial correlation between temperature and the Economic Freedom Index in poor countries, but not in rich countries, and there is no correlation between precipitation and the Economic Freedom Index. However, model 1 does not establish a causal relationship between the Economic Freedom Index and temperature in poor countries, as the model might omit confounding variables, i.e. variables which correlate with both the Economic Freedom Index and temperature. A potential confounding variable is the settler mortality in former

[8] The reason why we use a random effect model for estimation is that in model 3 we include a time invariant variable to the regressions; hence we cannot apply the fixed effect estimator to these models.

[9] The Poor Dummy is provided by Dell et al (2002); They defined a country as being poor if it has PPP GDP per capita which is below median GDP per capita in the first year that country enters the data. The Poor Dummy is missing for Myanmar in the Dell et al (2002) data, but in our regressions, we treat Myanmar as a poor country.

colonies, which has been used as an instrument for institutional quality in previous cross-sectional studies, (Acemoglu, Johnson, and Robinson 2001; Rodrik, Subramanian, and Trebbi 2004).

One drawback in augmenting the model with log settler mortality is the necessity to exclude all the countries for which we do not have information concerning log settler mortality[10]. We do, therefore not know if any potential difference is due to a different sample or due to the added explanatory variable. Therefore, as the next step, we re-estimate the model for countries for which we have data for log settler mortality. The results in model 2 are roughly the same as in model 1, and there are considerable adverse effects of temperature in poor countries.

[10] This implies that we would exclude all non-former colonies.

Table 2: Random effect models: The relationship between economic freedom and temperature

Dependent variable: Economic Freedom Index			
Explanatory variables	Model 1	Model 2	Model 3
Temperature	-0.0279*	-0.0348	-0.00786
	(0.0154)	(0.0295)	(0.0320)
Temperature x poor dummy	-0.0429***	-0.0378***	-0.0270**
	(0.00826)	(0.0102)	(0.0114)
Precipitation	0.00178	-0.00580	-0.00533
	(0.00763)	(0.00949)	(0.00941)
Log settler mortality			-0.307**
			(0.124)
Constant	6.396***	6.539***	7.196***
	(0.311)	(0.655)	(0.585)
Observations	2,783	1,727	1,727
Number of countries	96	60	60
Only countries with available settler mortality data	No	Yes	Yes
R-squared	0.355	0.300	0.374
Year Fixed effects	Yes	Yes	Yes
Effect of warming on institutional quality in poor countries	-0.0708***	-0.0726***	-0.0348
	(0.0133)	(0.0271)	(0.0329)

Panel robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Finally, in model 3, we augment model 2 with log settler mortality. Now, there is no partial correlation between temperature and the Economic Freedom Index in either rich nor poor countries, but there is a large negative partial correlation between log settler mortality and institutional quality.

It follows that there is no basis for claiming a causal link from current weather to institutional quality, at least for former colonies, and it is, therefore, appropriate to include both weather variables and the Economic Freedom Index in panel regressions. Otherwise, the omitted variable introduces a potentially serious bias.

Panel models with homogenous temperature effects on economic activity

In this section, we consider several panel regressions models, where we use log PPP GDP per capita as our dependent variables and estimate semi-elasticities of PPP GDP per capita relating to the weather variables and the Economic Freedom Index, invariant across all countries and time.

In all the empirical models that we consider, we include both year fixed effects and country fixed effects, i.e. we estimate the effects of with-in variation. The fixed effect-estimator has the property that the Nickell bias converges to zero as T approaches infinity, (Nickell 1981)[11]. In our setting, we have 33 years of data. Hence, Nickel-the bias is negligible. Also, we have not been able to find models where log GDP capita is conditionally stationary if we exclude country fixed effects, in which case we cannot compute the long-run effects of any of the covariates on GDP per capita. Hence, all our models in this section are estimated using the with-in estimator. We stress that the inclusion of a country fixed effect might come at a considerable cost, since most of the variation in temperature and Economic Freedom Index stems from between country variance, as was evident in table 1 and figures 1 and 2. Therefore, we will investigate the robustness of our results in a following section, using a modelling set-up without country fixed effects.

In table 3, we report results from varying the number of lagged dependent variables in equation (1), page 6, and excluding lags of the covariates. The purpose is to find a lag structure, which provides a conditional stationary dependent variable in order to compute the long-run effects on wealth of permanent shocks to the covariates.

[11] An alternative to using the fixed effect estimator is to use the Arrelano-Bond estimator (Arellano and Bond 1991). However, Monte-Carlo studies conducted by Hauck Jr and Waczeirg (2004) show that the Arellano-Bond estimator inflates the rates of convergence much more than the fixed estimator. In our models, the Arrelano-Bond estimator produces estimated rates of convergence around 20 per cent per year, which is a much faster estimated rate of convergence than any of the with-in estimators, and hence the with-in estimator is our preferred estimator. The results using the Arrelano-Bond estimator are available upon request.

Table 3: Fixed effects models, finding the appropriate lag structure

Dependent variable: Log GDP per capita					
Explanatory variables	Model 4	Model 5	Model 6	Model 7	Model 8
First lag of GDP per capita	0.937***	1.086***	1.077***	1.076***	1.072***
	(0.0110)	(0.0396)	(0.0346)	(0.0324)	(0.0321)
Second lag of GDP per capita		-0.157***	-0.124***	-0.138***	-0.143***
		(0.0340)	(0.0332)	(0.0356)	(0.0373)
Third lag of GDP per capita			-0.0291	0.0663*	0.0700*
			(0.0347)	(0.0355)	(0.0365)
Fourth lag of GDP per capita				-0.0861***	-0.0876***
				(0.0263)	(0.0319)
Fifth lag of GDP per capita					0.00113
					(0.0177)
Temperature	-0.00140	-0.00174	-0.00123	-0.00207	-0.00148
	(0.00277)	(0.00274)	(0.00272)	(0.00283)	(0.00284)
Precipitation	0.000140	0.000131	0.000239	0.000288	0.000390
	(0.000577)	(0.000564)	(0.000563)	(0.000580)	(0.000565)
Economic Freedom Index	0.0105***	0.0101***	0.00995***	0.00915***	0.00930***
	(0.00261)	(0.00254)	(0.00261)	(0.00256)	(0.00263)
Constant	0.533***	0.610***	0.643***	0.699***	0.698***
	(0.101)	(0.107)	(0.101)	(0.100)	(0.103)
Observations	2,736	2,689	2,642	2,595	2,546
Number of countries	96	96	96	96	96
R-squared	0.9959	0.9960	0.9959	0.9959	0.9959
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Estimated rate of convergence	0.0634***	0.0717***	0.0761***	0.0821***	0.087***
	(0.0110)	(0.0111)	(0.0107)	(0.0103)	(0.0105)
Long-run effect of temperature on	-0.0221	-0.0243	-0.0161	-0.0252	-0.0169
GDP per capita	(0.0438)	(0.0379)	(0.0356)	(0.0344)	(0.0325)
Long-run effect of precipitation on	0.00221	0.00183	0.00314	0.00351	0.00446

Table 3 - *continued*

Explanatory variables	Model 4	Model 5	Model 6	Model 7	Model 8
GDP per capita	(0.00907)	(0.00785)	(0.00740)	(0.00709)	(0.00651)
Long-run effect of the Economic Freedom	0.166***	0.141***	0.131***	0.116***	0.106***
Index on GDP per capita	(0.0422)	(0.0342)	(0.0318)	(0.0285)	(0.0283)
Unit root test	0.230	-0.0894	0.263	-0.856	-1.660
	[0.591]	[0.464]	[0.604]	[0.196]	[0.0485]

Panel robust standard errors in parentheses, p-values in square brackets.

*** p<0.01, ** p<0.05, * p<0.1

Table 3 reports that on a 5 per cent significance level, we only reject the null of a unit root for model 8, where we include five lags of the dependent variable; this is a quite notable result, as the fifth lag of the dependent variable is itself insignificant. However, in the time series literature it is sometimes argued that if unit root tests are used as a pretest, for example before considering cointegration, the appropriate significance level is perhaps as high as 20 per cent (Maddala and Kim 1998). If we use a significance level of 20 per cent, log GDP per capita is conditionally stationary in model 7, in which we include four lags of the dependent variables. The long-run marginal effects of all the covariates are roughly the same in model 7 and model 8. Since the main results are roughly the same in both, and the evidence for conditional stationarity is strongest in model 8, the latter will be our point of departure in the analysis in the following sections.

In model 8, the estimated rate of convergence is around 9 per cent per year, which is quite high, considering that the "iron rule" rate of convergence is around 2 per cent per year (Barro 2015). However, this is a consequence of using the country fixed effect estimator (Hauck Jr and Waczeirg 2004), which in turn is needed for log GDP per capita to be conditionally stationary. Hence, we must pay the price of an unreasonably high rate of convergence.

The long-run semi-elasticities are insignificant for the two weather variables, but the semi-elasticity concerning the Economic Freedom Index is roughly 0.106, which is a large value and highly significant. These results indicate that it is institutional quality and not weather variables, which are essential for the long-run wealth of a country. However, model 8 leaves out potential non-linear effects of temperature, which could imply that the marginal effects of temperature are significant in some countries.

Table 4: Fixed effect models

Dependent variable: log GDP capita			
Explanatory variables	Model 9	Model 10	Model 11
First lag of log GDP per capita	1.069***	1.072***	1.071***
	(0.0329)	(0.0322)	(0.0323)
Second lag of log GDP per capita	-0.140***	-0.143***	-0.141***
	(0.0378)	(0.0373)	(0.0373)
Third lag of log GDP per capita	0.0687*	0.0701*	0.0677*
	(0.0367)	(0.0366)	(0.0360)
Fourth lag of log GDP per capita	-0.0873***	-0.0877***	-0.0862***
	(0.0319)	(0.0319)	(0.0320)
Fifth lag of log GDP per capita	0.00136	0.00111	-0.000985
	(0.0178)	(0.0177)	(0.0175)
Temperature	0.00218	-0.000925	0.0126**
	(0.00348)	(0.00348)	(0.00523)
Temperature x Poor Dummy	-0.0142**		
	(0.00622)		
Precipitation	0.000294	0.000378	0.000241
	(0.000550)	(0.000554)	(0.000545)
Economic Freedom Index	0.00894***	0.00929***	0.00940***
	(0.00260)	(0.00262)	(0.00267)
Temperature x former colony dummy		-0.00169	
		(0.00548)	
Temperature square			-0.000485***
			(0.000161)
Constant	0.780***	0.707***	0.648***
	(0.111)	(0.106)	(0.101)
Observations	2,546	2,546	2,546
Number of countries	96	96	96
Year fixed effects	Yes	Yes	Yes
R-squared	0.9895	0.9957	0.9954

Table 4 - *continued*

Explanatory variables	Model 9	Model 10	Model 11
Estimated rate of convergence	0.0884***	0.0876***	0.0901***
	(0.0106)	(0.0105)	(0.0111)
Long-run effects of temperature in rich countries	0.247		
	(0.0395)		
Long-run effects of temperature in poor countries	-0.136***		
	(0.0581)		
Long-run effects of temperature in non-former colonies		-0.0106	
		(0.0387)	
Long-run effects of temperature in former colonies		-0.0298	
		(0.0508)	
Long-run effects of precipitation	0.00333	0.00431	0.00267
	(0.00628)	(0.00637)	(0.00607)
Long-run effects of the Economic Freedom Index	0.101***	0.106***	0.104***
	(0.0278)	(0.0283)	(0.0274)
Optimal temperature			13.025***
			(2.856)
Unit root test	-1.775	-1.582	-1.756
	[0.0380]	[0.0568]	[0.0395]

Panel robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Panel models with heterogeneous temperature effects on economic activity

Both Burke, Hsiang, and Miguel (2015) and Dell, Jones, and Olken (2012) find the marginal effects of temperature on economic growth to be heterogeneous, which is also the case in IAMs. We

therefore now consider models allowing the marginal effects of temperature on log GDP per capita to differ between countries. We report the results in table 4.

In model 9, we follow Dell, Jones, and Olken (2012) and assume different marginal effects of temperature on log GDP per capita in rich and poor countries. We do this by interacting temperature with the same Poor Dummy (i.e. countries with less than mean GDP in the first year). [12]. The estimated long-run semi-elasticity of the Economic Freedom Index is significant and numerically close to the estimates found in model 8. The long-run semi-elasticity of temperature is numerically large and significant for poor countries, but insignificant for rich countries.

A central concern in model 9 is the Poor Dummy being partially constructed based on the dependent variable, and hence it is not clear to what extent the large adverse marginal effects of warming in poor countries hold per construction[13]. To provide a tentative inspection of this question, we instead interact temperature with a former colony dummy in model 10[14]. The former colony dummy is not constructed based on log GDP per capita at any point in time, and hence if we find that the marginal effects of temperature do not differ between former colonies and non-former colonies, we take this as suggestive the numerically large marginal effects of temperature is a constructed result. Model 10 reveals that the marginal effects of temperature do not differ from zero, for both former and non-former colonies, and hence the results from model 9 should be interpreted with caution as they may hold per construction.

Another way to introduce heterogeneity in the marginal effects of temperature is to include temperature squared as in Burke, Hsiang, and Miguel (2015)[15].

Model 11 thus includes temperature squared in our panel regression[16]. Here we find that both the coefficients to temperature and temperature squared are statistically significant, and hence the relation between GDP per capita and the temperature seems to be a quadratic one, affirming the

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[12] We have interacted all the covariates with the Poor Dummy, but the interaction terms are all insignificant, expect for temperature. The results are available upon request.

[13] We note that Dell, Jones, and Olken (2012) use the growth rate of GDP per capita as the dependent variable, and hence the Poor Dummy is not constructed based on their dependent variables. Therefore, Dell, Jones, and Olken (2012)'s finding that the economic effects of temperature are significant in poor countries is less likely to hold per construction than in our setting.

[14] We have interacted all of covariates with the former colony dummy, but none of the interactions are significant on a 5 per cent significance level.

[15] Burke, Hsiang, and Miguel (2015) also interacted temperature and temperature squared with a Poor Dummy, and they found that the marginal effects of temperature do not differ between rich and poor countries given that the temperature is the same for the two countries. Hence, in model 11 we do not interact any of our variables with a Poor Dummy.

[16] We have squared all the covariates, but it is only squared temperature which is significant.

structure of damage functions in IAMs. The optimal temperature is around 13 degrees Celsius; this is the same value as in Burke, Hsiang, and Miguel (2015).

Model 11 suggests that both institutional quality and temperature affect the level of GDP per capita. The effect found for GDP corresponds to a semi-elasticity of 0.104, i.e. a one-point increase on the (ten points maximum) Economic Freedom Index will increase GDP per capita by 10.4 per cent in any given country and given point in time.

The effect of warming, on the other hand, depends on the initial temperature level. One degree roughly corresponds to the room left for a further increase in global average temperature, if the post-industrialization temperature rise is to be two degrees Celsius[17]. For global GDP[18], a uniform one-degree Celsius increase in global temperature would decrease GDP by 3.4 per cent; this is a rather high estimate compared to the literature in general; Nordhaus and Moffat (2017) report an estimated loss of global GDP of just 2 per cent from a two degrees Celsius temperature rise[19].

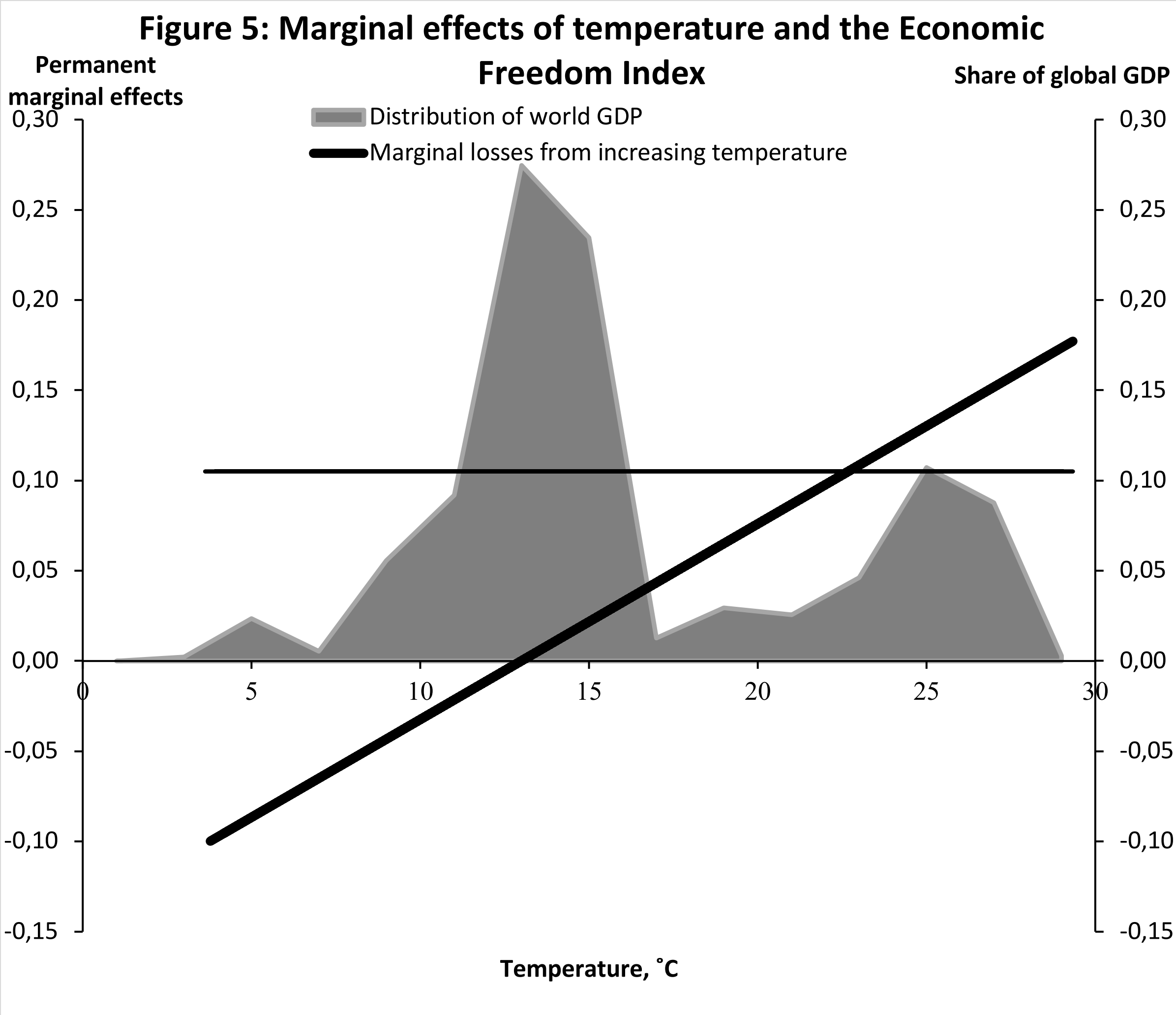
Never-the-less, the estimated effect of one-degree Celsius temperature rise is dwarfed by a one-point decrease in institutional quality, as measured by the Economic Freedom Index. Figure 5 depicts the temperature dependent semi-elasticity[20] for a range of initial temperature levels. It also includes a distribution of global GDP.

[17] The Paris Accord aim is to limit the post-industrialization temperature rise to 1½ - 2 degrees Celsius.

[18] Note, that the estimated semi-elasticities are the semi-elasticities for GDP per capita and not GDP. However, if we assume that the population size is not affected by any of the variable of interest, the semi-elasticity for GDP for some variable is the same as for GDP per capita.

[19] The reported effect is from a three degrees Celsius temperature rise, compared to pre-Industrial levels.

[20] Note that we plot the" losses" from increasing temperature, so the effects are negative for cold countries (that benefit from increasing temperature) and positive for hot countries.



As can be seen from figure 5, a one-point decrease in the Economic Freedom Index would have a greater impact on GDP per capita than a one-degree increase in temperature for around 79 per cent of the World measured by GDP.

Furthermore, as was seen in figure 4, the potential for institutional improvement is higher in warm countries. So even for those countries, institutional reforms could be at least as important as the effect of containing climate change.

Robustness checks

In this section, we provide some robustness checks. This is a special concern, since, as we will show, lack of robustness is an issue with the two previous top down-studies.

We consider two kinds of robustness checks: Robustness checks of our log level models[21] and robustness checks which relate to the economic growth rate models (Burke, Hsiang, and Miguel 2015; Dell, Jones, and Olken 2012). Overall, the log-level models seem more robust than the growth rate models, which provides yet another argument for preferring log level models to growth models.

The point of departure for our robustness checks is model 11, which includes temperature squared in the regressions. The reason why this is our preferred model is that temperature squared is significant and, unlike model 9, the heterogeneous economic effects of temperature have no risk of holding per construction. Table 5 demonstrates robustness checks.

[21] We do not use World Bank data for log chained PPP GDP per capita as a robustness check, since our panel will be quite short (the series starts at 1990) and hence the Nickell bias will be substantial. Instead we note that both Burke, Hsiang, and Miguel (2015) and Dell, Jones, and Olken (2012), provide robustness checks which suggest that their results are not sensitive to the choice of national account data from Word Bank or Penn-World table. Also, we do not consider a balanced panel, since we would have to start the panel at around 1990, following the fall of the Berlin Wall and the breakdown of the Soviet Union; hence we would once again have problems with a short panel and a substantial Nickell-bias.

Table 5: Fixed effects models, robustness checks

Dependent variable: Log GDP per capita				
Explanatory variables	Model 12	Model 13	Model 14	Model 15
First lag of log GDP per capita	1.081***	1.053***	1.105***	1.071***
	(0.0303)	(0.0324)	(0.0446)	(0.0325)
Second lag of log GDP per capita	-0.153***	-0.136***	-0.223***	-0.141***
	(0.0377)	(0.0384)	(0.0467)	(0.0376)
Third lag of log GDP per capita	0.0597*	0.0790**	0.0881*	0.0683*
	(0.0358)	(0.0388)	(0.0476)	(0.0362)
Fourth lag of log GDP per capita	-0.0777**	-0.0818**	-0.0936**	-0.0863***
	(0.0311)	(0.0313)	(0.0368)	(0.0321)
Fifth lag of log GDP per capita	0.000335	-0.0147	0.0121	-0.00146
	(0.0174)	(0.0159)	(0.0197)	(0.0176)
Temperature	0.0156***	0.00461	0.0120**	0.0127**
	(0.00466)	(0.00583)	(0.00531)	(0.00565)
First lag of temperature	-0.00698			
	(0.00584)			
Temperature squared	-0.000579***	-0.000213	-0.000485***	-0.000485***
	(0.000166)	(0.000185)	(0.000178)	(0.000167)
First lag of temperature squared	0.000223			
	(0.000221)			
Precipitation	0.000160	9.06e-05	-4.19e-05	0.000274
	(0.000612)	(0.000564)	(0.000598)	(0.000558)
First lag of precipitation	-0.000492			
	(0.000694)			
Economic Freedom Index	0.0117*	0.00830**	0.00858***	0.00939***
	(0.00652)	(0.00320)	(0.00237)	(0.00279)
First lag of the Economic Freedom Index	-0.00335			
	(0.00696)			
Constant	0.688***	0.812***	0.866***	0.640***
	(0.107)	(0.115)	(0.168)	(0.103)

Table 5 - *continued*

Explanatory variables	Model 12	Model 13	Model 14	Model 15
Observations	2,499	2,546	1,961	2,430
Number of countries	95	96	72	92
Year FE	Yes	No	Yes	Yes
Region times year fixed effects	No	Yes	No	No
R-squared	0.9956	0.9921	0.9952	0.9951
Estimated rate of convergence	0.0898***	0.1001***	0.111***	0.0900***
	(0.0111)	(0.0120)	(0.0182)	(0.0111)
Long lasting effects of precipitation	-0.00370	0.000902	-0.00378	0.00304
	(0.00783)	(0.00561)	(0.00540)	(0.00623)
Long lasting effects of the Economic Freedom Index	0.0931***	0.0826***	0.0774***	0.104***
	(0.0299)	(0.0292)	(0.0192)	(0.0285)
Optimal temperature	12.157**	10.852	12.374***	13.131***
	(5.596)	(8.966)	(3.158)	(3.0974)
Unit root test	-0.785	-0.918	-3.326	-1.814
	[0.216]	[0.179]	[0.000553]	[0.0349]

Panel robust standard errors in parentheses, p-values in squared parentheses

*** p<0.01, ** p<0.05, * p<0.1

Model 12 is like model 11, but we add one lagged value of all the covariates (see equation (1)). We find no evidence supporting conditional stationarity of log GDP per capita; this emphasizes that conditional stationarity of the dependent variable is sensitive to the lag structure of the empirical model. As model 11 is more parsimonious than model 12 and is it is consistent with conditional stationarity of the log GDP per capita, model 11 is preferred to model 12.

In model 13, we use the same type of deterministics as Dell, Jones, and Olken (2012), i.e. we include country fixed effects and interact the year fixed effects with region dummies. Here we do not find evidence supporting conditional stationarity of log GDP per capita. This stresses the importance of the deterministic part of panel models with temperature as an explanatory variable. A more parsimonious model, like model 11 in this paper, is consistent with conditional stationarity of log GDP per capita and hence it preferred to the more complicated models presented in Dell, Jones, and Olken (2012).

In model 14, we drop the countries from South Sahara, which are usually both hot and poor. The results are roughly the same as in model 11, although the long-run effects of the Economic Freedom Index are somewhat lower than in our preferred model.

Finally, in model 15, we drop Neo-Europe (USA, Canada, Australia, and New Zealand) from our sample. Again, the results are in line with those from model 11.

Overall, the main conclusions from the log level models, i.e. long-run semi-elasticity of the economic freedom index is 10.4 per cent, and the optimal temperature is around 12-13 degrees Celsius.

As already mentioned, conditional stationarity requires the inclusion of country fixed in models using GDP levels as the dependent variable. Hence, the estimators are driven by the with-in country variance of independent variables, leaving out the considerable between country variation. To exclude country fixed effects, we have re-estimated the models, using GDP per capita growth rates instead, as in Burke, Hsiang, and Miguel (2015) and Dell, Jones, and Olken (2012). Using growth rates is, however, less plausible since the fitted values of the growth rate might be trending. Furthermore, shocks to temperatures or institutional quality could lead to substantial and increasing divergences in GDP per capita levels over time. Therefore, the re-estimation serves mainly as a robustness check.

In table 6 we consider re-estimates the models in Burke, Hsiang, and Miguel (2015) and Dell, Jones, and Olken (2012), but we include only year fixed effects in the estimation. The reason why we do not include country fixed effects in the estimation is the quite low with-in variation for temperature.

Table 6: Random effect models: growth regressions

Dependent variable: Yearly GDP per capita growth				
Explanatory variables	Model 16	Model 17	Model 18	Model 19
Temperature (1)	0.100	0.357	0.00188	0.0891
	(0.199)	(0.232)	(0.0691)	(0.0995)
Temperature x Poor Dummy (2)	-1.157***	-1.828***		
	(0.403)	(0.592)		
First lag of temperature (3)	-0.190	-0.375		
	(0.202)	(0.231)		
First lag of temperature x Poor Dummy (4)	1.138***	1.823***		
	(0.404)	(0.591)		
Precipitation (5)	-0.00690	0.00679	0.0161	-0.00707
	(0.0361)	(0.0530)	(0.0193)	(0.0277)
First lag of precipitation (6)	0.0197	-0.0226		
	(0.0373)	(0.0538)		

Table 6 - *continued*

Explanatory variables	Model 16	Model 17	Model 18	Model 19
Economic Freedom Index (7)		1.589**		0.438***
		(0.680)		(0.143)
First lag of the Economic Freedom Index (8)		-1.232*		
		(0.715)		
Temperature squared (9)			-0.00339	-0.00325
			(0.00211)	(0.00314)
Constant	6.082***	2.423*	5.440***	1.478
	(1.032)	(1.338)	(1.110)	(1.454)
Observations	5,575	2,687	5,575	2,783
Number of countries	120	95	120	96
Year FE	Yes	Yes	Yes	Yes
R-squared	0.0509	0.0596	0.0492	0.0533
(Same year) Level effect of warming	-1.057***	-1.471**		
in poor countries ((1)+(2))	(0.355)	(0.577)		
Growth effect of warming	- 0.0893***	-0.0178		
in rich countries ((1)+(3))	(0.0243)	(0.0317)		
Growth effect of warming	-0.109***	-0.0233		
in poor countries ((1)+(2)+(3)+(4))	(0.0183)	(0.0311)		
Growth effect of precipitation ((5)+(6))	0.0128	-0.0158		
	(0.0213)	(0.0277)		
Growth effect of the Economic Freedom Index ((7)+(8))		0.356**		
		(0.168)		
Optimal temperature			0.277	13.703***
			(10.019)	(4.674)

Panel robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Model 16 corresponds to model 3 in Dell, Jones, and Olken (2012), but we handle the deterministics differently. In our specification, we find persistent adverse growth effects of warming in both rich and poor countries; this is a stronger result than in Dell, Jones, and Olken (2012), who only found negative persistent growth effect of warming in poor countries. Hence, the results from Dell, Jones, and Olken (2012) are sensitive to the deterministic part of the model, which is unfortunate since it is not possible to test if the growth rate is conditionally stationary. These considerations provide a strong argument for using log GDP per capita as the dependent variable and test if it is conditionally stationary.

In model 17, we augment model 16 with the Economic Freedom Index. Now we no longer find persistent growth effects of temperature, but we do find a level effect of warming in poor countries. Hence, (Dell, Jones, and Olken 2012)'s finding that temperature shocks have persistent growth effects in poor countries seems to be spurious.

Model 18 corresponds to the model in Burke, Hsiang, and Miguel (2015). In our specification, we find no support of a quadratic relationship between economic growth and temperature. Also, the "optimal temperature" is only around zero degrees Celsius and highly insignificant.

In model 19, we augment model 18 with the Economic Freedom Index. Again, we find no support of a quadratic relationship between economic growth and temperature. Hence, none of the growth regressions is consistent with a quadratic relationship between temperature and GDP per capita growth and the results presented in Burke, Hsiang, and Miguel (2015) are due to the specific way they handle the deterministic part of the model.

In conclusion, institutional quality displays considerable robustness in its correlation with GDP growth rates, just as was the case with GDP levels. The correlation between temperature and growth rates, however, does not appear robust, even if still quadratic. If we correct for institutional quality, the correlation is statistically insignificant.

Can the relationship between institutions and wealth be given a causal interpretation?

In this section, we follow Acemoglu, Johnson, and Robinson (2001) and Rodrik, Subramanian, and Trebbi (2004) and use log settler mortality as an instrument for institutional quality to bypass the problems with reversed causality, hence giving the economic effects of the Economic Freedom Index a causal interpretation. We note that we cannot include country fixed effects in this model since log settler mortality is a time-invariant variable. We only report results from growth rate regressions. The reason why we do not apply log level models, even though these are our preferred models as discussed earlier, is that in the first stage regression of the Economic Freedom Index, we would have to include lags of log GDP per capita. The problem with including lags of log GDP per capita in the first stage regression is that log GDP per capita has a clear trend, which could generate a trend in the fitted values of the Economic Freedom Index. This would be problematic since the index, unlike GDP, is not open-ended. Therefore, we only focus on the growth regressions in the following.

Table 7 reports the results from the growth regressions.

Table 7: Two stages least squares estimation, random effect models

	Model 20	
Explanatory variable	First stage	Second stage
Temperature (1)	-0.00786	0.0380
	(0.0346)	(0.0973)
Temperature x poor dummy (2)	-0.0270**	0.0351
	(0.0123)	(0.0269)
Precipitation (3)	-0.00533	-0.0167
	(0.00999)	(0.0445)
Log settler mortality (4)	-0.307**	
	(0.134)	
Economic freedom index (5)		1.390*
		(0.698)
Constant	7.196***	-4.385
	(0.639)	(5.044)
Number of observations	1,727	1,702
Number of countries	60	60
Year fixed effects	Yes	Yes
R-squared	0.374	0.0438
Effect of temperature on the economic freedom index	-0.0348	
for poor countries ((1)+(2))	(0.0354)	
Effect of temperature on growth for poor countries ((1)+(2))		0.0731
		(0.0985)

Jack-knife standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Model 20 is a model where we follow Dell, Jones, and Olken (2012) and interact temperature with a poor country dummy. Note, we do not add lagged values of the covariates in these regressions. The reason being that we would have more than one endogenous variable (i.e. the Economic Freedom Index and its lagged values), while we have only one instrument.

From the first stage regression, we see that log settler mortality is a valid instrument for the Economic Freedom Index, and consequently we proceed with the second stage regression. Here we find a significant effect of the Economic Freedom Index on growth, which has a causal interpretation: The Economic Freedom Index affects growth, not the other way around.

Conclusions and policy implications

In this paper, we have moved from panel growth model to panel level models, considering the effects of weather variables on economic performance, and we augmented these regressions with the Economic Freedom Index as a measure of institutional quality. We find a very robust, significant and substantial effect of institutional quality on growth, implying a semi-elasticity of .104. In our preferred model, we find a significant average (global) semi-elasticity of -0.034 of temperature on growth; for individual countries, the semi-elasticity depends on initial temperature levels, since the estimated effect is quadratic. The effect of temperature is large compared to the empirical literature, but for most of the countries, the effects of institutional quality dwarf the effects of temperature. Also, we provide suggestive evidence of a causal relationship between the Economic Freedom Index and long-run wealth.

Our study has important policy implications: Since both temperature and economic freedom are essential for conditions for wealth, there is a case for both reducing global warming and improving institutional quality. In this context, it is especially interesting to consider developing countries, since these countries are generally both hot, (cf. figure 1) and have considerable room for improving their institutional quality (cf. figure 3). For many years a prerequisite for receiving foreign aid has been a commitment by the developing country to improve its economic policy regime according to the Washington Consensus (Williamson 2004). Even given this focus on the institutional quality, in the literature, there has been serious doubts if foreign aid is net-beneficial to the recipient countries (Arvin and Lew 2015; Deaton 2013)[22] due to adverse effects on institutional quality. Therefore, it seems crucial not to lower the requirements to reform institutions and economic policies. However, in recent years, there has been an increasing drift towards "climate foreign aid", which could compromise the institutional focus of development policies (Bloomberg 2018).

[22] This could, for example, be the case if foreign aid helps incompetent and corrupt leaders to stay in power in the developing countries. Also, foreign aid might release some of the pressure for improving the institutional quality in these countries. Finally, the foreign aid could be used for rent-seeking, in the sense that the leaders of the developing countries could use the foreign aid for the projects which are profitable for themselves but does not increase wealth for the country.

Developed countries themselves have embraced climate change policies, which are not always cost-effective nor conform with market incentives and institutions. Those policies include “command-and-control” regulation, direct subsidies to specific technologies and industries and non-uniform emission taxes (see e.g. OECD 2018). It is well recognized in economic theory that efficient climate policies require a uniform price on GHG emissions (taxes or tradable emission permits), ideally on a Global scale, but also when pursuing national goals (e.g. Golosov et al. 2014). Uniform emission prices would internalize the GHG externality without compromising economic institutions. On the contrary, if ambitious goals of reducing GHG emissions on the scale envisioned by the Paris Accord are pursued by further command-and-control, subsidies and non-uniform GHG prices, it could be at the expense of the institutional and policy regime framework as measured by the Economic Freedom Index.

The results of this study provides an additional reason to choose market based climate policies, such as advocated by many economists, including the bipartisan “economists’ statement on carbon dividends” (Wall Street Journal 2019) recommending a general carbon tax and scrapping command-and-control regulation.

In many countries, institutional change could have more impact on growth than either climate change or policies to combat climate change. However, the two could be linked by a formal commitment to perform institutional reforms powerful enough to at least off-set the negative growth effect of climate change and climate policies. E.g. the Danish 2019 Climate Act Deal includes a goal that climate policies do not reduce growth, which could be achieved by off-setting reforms (Klima-, Energi- og Forsyningsministeriet 2019).

Deep institutional features such as the rule of law and anti-corruption could be difficult to change in the shorter run. However, other institutional aspects covered by the Economic Freedom Index would be more flexible, such as removing non-tariff barriers to trade, deregulation of labor and product markets, stable monetary arrangements, more open competition and tax reform with lower, less distortionary tax rates. Packaging such policies with climate policies might open possibilities for new reform coalitions.

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