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Francesco Bosello, Fondazione Eni Enrico Mattei (FEEM), Euro-Mediterranean Centre on Climate Change (CMCC) and Università degli Studi di Milano
Shouro Dasgupta, Fondazione Eni Enrico Mattei (FEEM), Università Ca' Foscari Venezia and Euro-Mediterranean Centre on Climate Change (CMCC)

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Summary

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Keywords: Climate Change Damages, Adaptation, Panel Granger Causality

JEL Classification: C19, Q54, Q56

Address for correspondence
Francesco Bosello
Fondazione Eni Enrico Mattei
Isola di San Giorgio Maggiore 8
30124 Venice
Italy
E-mail: francesco.bosello@feem.it

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Francesco Bosello*[1, 3, 4] and Shouro Dasgupta†[1, 2, 3]

[1]Fondazione Eni Enrico Mattei (FEEM)
[2]Università Ca' Foscari Venezia
[3]Euro-Mediterranean Centre on Climate Change (CMCC)
[4]Università degli Studi di Milano

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* francesco.bosello@feem.it
† shouro.dasgupta@feem.it

Summary

1. Introduction and Background

The total estimated damage from climate related disasters between 2011 and 2013 was US$ 641 billion while the average number of deaths and people affected between 2003 and 2012 were 106,000 and 216 million, respectively. How will these damages and fatalities change in the coming years? Under the theoretical view point, expectations of both increasing and decreasing trends can be supported. Indeed, on the one hand development associated to higher population density, physical capital, and ultimately GDP would itself determine a higher exposure to climate stressors and thus expected damages. This trend can be exacerbated by climate change that can increase the frequency and intensity of some form of climatological events (IPCC, 2012). On the other hand, development associated to more advanced technologies, knowledge and resource availability would determine a higher adaptive capacity and thus lower expected damages.

A number of papers have studied the determinants of natural disasters originating a rapidly growing body of research. The related, mostly econometric literature has focused on the linkages between damages and different indicators of economic development. The general finding is that developed societies tend to be less vulnerable; however, the relation between vulnerability and development is not always straightforward with studies pointing to non-linear or even negative patterns. In a seminal paper Albala-Bertrand (1993) argues that countries with weaker economies are more affected by climate related disasters. Horwich (2000) also suggests that the level of wealth is critical for a country's response to a natural disaster. Using quantile regression, Keefer et al. (2011) test differential impacts of earthquakes, floods, and tropical cyclones across various damage bins on disaster propensity. They find that mortality due earthquakes are lower in countries with high payoffs to mortality prevention and mortality is higher in autocracies and in more corrupted countries but without controlling for many other relevant socioeconomic variables. Mendelsohn et al. (2012) found damage elasticity to income to be 0.42 and population density to be -0.20 concluding that both provide an evidence of adaptation linked to development.

Kellenberg and Mobarak (2008) identify of a nonlinear relationship between economic development and vulnerability to damages from natural disasters, with risk initially increasing with higher incomes as a result of changing behaviors. Cavallo et al. (2010) using simple regression techniques conclude that countries with higher population, land area, and GDP are more exposed and hence suffer higher damages from earthquakes. Their findings are thus conflicting to the argument that richer countries have more adaptive capacity.

A stream of literature (Kahn, 2005; Skidmore and toya, 2007; Stromberg, 2007; Raschky, 2008; and

Plumper and Neumayer, 2009) focuses on the role of political and institutional variables. The general finding is that increases in education, trade openness, financial sector strength, coupled with better institutions and stable democratic regimes help reduce the impact of disasters. A few papers have also explored the link between political accountability and damages from natural disasters (Besley and Burgess, 2002; Eisensee and Stromberg, 2007 and Healy and Malhotra, 2009) finding that greater accountability tends to lower damages.

One criticism of the current literature is the fact that often social, macroeconomic, institutional and political regimes characteristics have not been explored together - thus raising the possibility of missing variables bias. Furthermore, the studies mostly use annual means of socioeconomic data and do not consider the possibility of heterogeneous adaptation or maladaptation across countries.

With this paper we try to answer two questions. First, which effect prevails in determining climate vulnerability across societies? Is it the increasing exposure due to more assets at risk or the increasing adaptive capacity effect? Second, which is the direction linking damages and development? Are the former driving the latter or vice versa? For this purpose we analyze the determinants of a set of weather/climate damages associated to: drought, extreme temperatures, wildfire, floods, landslides, and storms[1] between 1980 and 2012. We address some of the limitations of the existing literature by:

- Including several social, macroeconomic and institutional variables to empirically test the evidence of adaptation/adaptive capacity estimating damage elasticity to income and population density.
- Not assuming aprioristically linearity among the variables nor homogeneity across countries with different wealth and development levels.
- Furthermore, providing a panel Granger causality analysis to determine if the relationship between income and climatological damages is bidirectional.

We find evidence of adaptive capacity in a "weak" form both in terms of income and population density elasticities over our entire sample. That is, damages are in fact increasing with income and population, but less than proportionally. There is also evidence of countries improving their adaptive capacity over the long run, but of maladaptation occurring in the short run. Repeating the analysis splitting the sample by per-capita income levels, we find that higher income countries show adaptive capacity in a "strong form", i.e. damages decrease with GDP, while lower income countries highlight exactly the opposite behavior. Finally, using Granger causality tests for panel data, we find evidence of increase in GDP per capita Granger causing climate

[1] As coded in EM-DAT database.

related damages for lower income countries, but not in higher income countries.

2. Methodology and Data

The aim of the paper is to explain climate related economic damages by controlling for socioeconomic indicators along with measures of risk, institutional capacity, and stability of democratic regimes. As a conceptual starting point, we assume that countries solve an optimization problem with the goal to minimize total costs from climate disasters. Without adaptation, for a particular climatological disaster, *c*, countries' damages, D_c, can be written as[2];

$$D_c = \alpha_1 \cdot Y \cdot \alpha_2 \cdot Pop \cdot CD_c^{\alpha_3} \qquad (1)$$

According to (1) damages will be higher as income, *Y*, and population density, *Pop*, increase. In (1) CD_c represents characteristics of the climatological disaster *c*. However, adaptation can protect against damages from disasters. Assuming that adaptation (expressed as the capacity to reduce the damage) also depends positively on income, population density, an adaptation function can be expressed as;

$$A = \gamma_1 \cdot Y^{\gamma_1} \cdot Pop^{\gamma_2} \qquad (2)$$

Finally, total damages from climatological disasters can be written as a multiplicative function of the two functions expressed above;

$$TD_c = A \cdot D_c = \alpha_1 \cdot \gamma_1 \cdot Y^{1-\gamma_1} \cdot \alpha_2 \cdot Pop^{1-\gamma_2} \cdot CD_c^{\alpha_3} \qquad (3)$$

In (3) the exponents of (2) appear with the inverted sign as adaptation lowers damages. For the purposes of this paper, we focus on income/wealth and population density as primary determinants of adaptive capacity. We assume that $\gamma_1 = \gamma_2 = 0$ in (3) suggests no evidence of adaptation. In other words, if the damage elasticities of income and population density are equal to 1 then it can be concluded that no adaptation has taken place. However, if the coefficients of income and population density elasticity are lower than 1 or negative then there is evidence of adaptation. We call "weak" adaptation the former case with damages increasing, but less than proportionally with income and population density, and "strong" adaptation the latter with damages decreasing with income and population density. On the other hand, if the elasticities are greater than 1, meaning that increases in income and population density will lead to more than proportional increases in damages from climate related disasters then we have evidence of maladaptation.

[2] Adapted from Schumacher and Strobl (2011).

Equation (3) can be conveniently transformed in log-log form and estimated with fixed effects controls to control for time-invariant effects, and reduce the threat of omitted variable bias. In our case, including fixed effects, controls for the average differences across countries in any observable or unobservable predictors. Fixed effects models are also based on less restrictive assumptions than random effects as they allow unobservable variables to have whatever associations with the observed variables regardless of whether they have been explicitly modelled or not (Angrist and Pischke, 2009). The general specification with country α and time γ effects can be written as:

$$d_{it} = X_i\beta + R_{it}\delta + X\beta_{it} + \alpha_i + \gamma_t + \epsilon_{it} \quad (4)$$

Where d_{it} is the log total damages in country *i* from climate related disasters in the year *t*, *R* is a measure of risk to a climate hazard in a country *i* in the year *t*, while *Xi* is a log vector of socioeconomic characteristics of country *i* in a given year. More specifically, the explanatory variables used are as follows;

Log of GDP per capita: It is used as an indicator for wealth and income of a country and thus indirectly of its potential adaptive capacity. As mentioned above, damage elasticity to GDP provides us with an indication of the existence of adaptation.

Log of population density: It is also meant to signal evidence of adaptive capacity should a country's damages increase less than proportionally with it.

The Polity index: It examines concomitant qualities of democratic and autocratic authority in governing institutions and incorporates component measures such as key qualities of executive recruitment, constraints on executive authority, political competition and changes in the institutionalized qualities of governing authority. It essentially captures those mixed traits by subtracting a country's rank order score on autocracy from its rank order score on democracy. This indicator is highly sensitive (it employs a 21 point scale). Moreover, it allows considering both the degree and the duration of democracy in any given country-year. It is meant to capture if and how the quality of institutions influences the damage and therefore its role in determining a country adaptive capacity.

Government expenditure as a share of GDP: It should capture the weight and interventionism of the public sector in the economy. It is included to investigate the effectiveness of government assistance and to some extent the impact of government size on damages.

The share of agricultural sector of GDP: It is used as an indication of a country's sensitivity to climatological disasters. The idea is that agriculture is a typical climate-dependent activity, therefore, the higher the share of agriculture's contribution to GDP of a country, the higher the risk of damages due to climatological disasters for that country.

Risk: Following Adger et al. (2004) we define this variable as the ratio of the number of people killed to the number of people affected by climatological disasters. This is included as an indicator of a country's vulnerability/sensitivity to climatic damages and is used as a proxy indicator for climatic risk for the population.

Openness is defined as the share of a country trade as percentage GDP3. It is an index of a country's integration with the global economy and is included to test if access to international markets, allowing easier inflow of foreign goods and investments, can act as a smoothing factor on its damages.

Temperature and precipitation are indicators of a country's exposure to the climate as climatological events are affected by both rising means and rising variability of these variables (Schär et al., 2004).

Our response variable is the natural log of US dollar denominated damages from natural and climatological disasters - drought, extreme temperatures, wildfire, floods, landslides, and storms. Our dataset is an unbalanced panel combining data from three datasets (climate disaster, socioeconomic, and climatic) between 1980 and 2012 for 104 countries. Damages from climatological disasters at the country level are taken from the EM-DAT (2012) database, and matched with World Development Indicators (World Bank, 2013) that provide all the macroeconomic and socioeconomic indicators. Data for democratic regime qualities have been taken from the Polity IV database (Marshall and Jaggers, 2002 and Polity IV, 2013). Data on temperature and precipitation derive from Global Historical Climatology Network (GHCN-M) version 2 (Peterson and Vose, 1997) for precipitation and version 3 for temperature (Lawrimore et al., 2011).

As with most econometric analysis, measurement errors are of concern. Since damages suffered from disasters are difficult to quantify, it is possible that some measurement errors are present in the EM-DAT database (2012). However, a number influential papers state the reporting standards of this particular database are acceptable and in order for a disaster to be included it must be meet a number of criteria. Furthermore, we use the damages data only as the dependent variable and as such the covariates are free from bias. While it could be argued that endogeneity remains an issue, we assume, in the first round of estimates, that GDP per capita and population density are exogenous. Then, we examine the determinants of climate disasters and test if adaptive capacity differs between the short and long run by exploring different lag structures of the covariates. Finally, we test explicitly the direction of the link between the dependent and the explanatory. All the specifications used, consider heterosckedasticity corrected standard errors.

[3] (EXPORT+IMPORT)/GDP

3. Results and Discussion

3.1. Mean Regression Framework

Table 1 reports the result of the simpler fixed effect models without lagged variables among the explanatory. Statistically significant income elasticities turn out to be robust across the models, with values ranging from 0.581 to 0.739. This suggests that as income of countries increase, damages from climatological disasters do not increase proportionally. Thus in the overall dataset, there is evidence of what we call "weak" adaptive capacity among countries with respect to income. It is likely that as a country's income increases, it is able to allocate greater funding towards adapting ex ante and ex post to climatological damages, e.g. constructing dams to protect against flood damages and rehabilitation of population living in coastal areas. Nonetheless, it is not possible to offset completely the higher exposure given by the more assets at risk.

In Table 1 in columns 2 and 3, coefficients for log of population density are also statistically significantly positive, and lower than one. This further provides evidence of adaptation and suggests that an increase in population density does not bring about a proportionate increase in climatological damages. This could be due to greater precautions being taken in densely populated and highly urbanized areas and governments undertaking more programs and projects to protect against climatological disasters.

Column 3 also shows, in accordance with intuition, that the larger the agricultural share in GDP, the higher the damages from climatological disasters. This is a consequence of a higher share of the economy particularly sensitive to natural disasters such as floods and droughts. The polity variable is negative and statistically significant, suggesting that stability and democratic qualities of regimes plays an important role in helping to reduce damages from climatological disasters. The same holds for the openness index which suggests that well developed trade relationships can help a country to smooth negative consequences of climate disasters. This can happen through an easier substitution of foreign demand and supply for the domestic ones should the latter be negatively affected by climate impacts and also, more directly, through an easier access to foreign aids. However, the coefficients for the share of government expenditure of GDP and risk are not statistically significant.

Table 1: Mean Regressions: Entire Panel

Variables	Dependent Variable: Log of Damages		
Log of GDP per capita	0.739***	0.631***	0.581***
	(-0.075)	(-0.073)	(-0.089)
Log of Population Density	0.125	0.153*	0.192**
	(-0.091)	(-0.083)	(-0.091)
Govt. Exp./GDP		0.003	0.006
		(-0.02)	(-0.022)
Risk		0.0123	0.019
		(-0.023)	(-0.023)
Agriculture Sector/GDP			0.013**
			(-0.001)
Openness			-0.501**
			(-0.141)
Polity			-0.019**
			(-0.007)
Constant	11.14***	1.20***	10.56***
	(-0.812)	(-0.755)	(-0.81)
Country FE	Yes	No	Yes
Year FE	No	Yes	Yes
Observations	1,022	985	972
Number of Countries	104	95	91

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

3.2. Long-Run Variation

In this section we explore the impact of lagged covariates on climatological damages and attempt to highlight any differential impact between the short and the long run. We also include temperature and precipitation as indicators of climatic exposure variables. The first striking difference with the static analysis reported in Table 1 is that the coefficient for contemporaneous income elasticity in Table 2 is greater than one and statistically significant, suggesting evidence of maladaptation in the short-run. However, the elasticity is lower than one in the long-run. This seems to point out that adaptive capacity of countries does improve with respect to income, but that this is a process requiring time. This finding is strengthened by the coefficient for population density elasticity; it is just slightly lower than one in the short-run, but much lower than one in the long-run, providing further evidence that adaptive capacity is a dynamic process. In the specific case of population this could indicate more protective adaptation and development programs being undertaken over time in areas with high population density.

Table 2: Regressions with Lagged Covariates

Variables	Dependent Variable: Log of Damages
Log of GDP per capita	1.491*** (-0.410)
Log of Population Density	0.792** (-0.044)
Govt. Exp./GDP	0.061 (-0.520)
Risk	0.026 (-0.023)
Agriculture Sector/GDP	0.018 (-0.013)
Openness	-0.322* (-0.145)
Polity	-0.011 (0.059)
Lagged Log of GDP per capita	0.660*** (-0.077)
Lagged Log of Population Density	0.330** (-0.083)
Lagged Govt. Exp./GDP	0.019*** (-0.003)
Lagged Risk	0.03 (-0.023)
Lagged Agriculture Sector/GDP	0.013** (-0.001)
Lagged Openness	-0.511 (-0.143)
Lagged Polity	-0.013** (-0.009)
Log of Temperature	0.007** (-0.001)
Log of Precipitation	0.003** (-0.019)
Constant	5.642 (-6.335)
Observations	776
Country FE	Yes
Year FE	Yes
Number of Countries	91

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Results in Table 2 also show that government expenditure is positive and significant only in the long run. This outcome, similar to that of Toya and Skidmore (2007) seems to point out that countries with higher share of public expenditure over GDP tend to dynamically experience higher climate related losses. This can be explained as a signal of lower efficiency of the public vs the private sector. In our sample this behavior can be driven by the presence of developing countries more easily characterized by ineffective relief efforts and corruption in government programs. Similarly, but with opposite effect, regime characteristics: democratic regimes seem to be less vulnerable to climate damages, but this relation is significant in the long-run, and with no effect in the short- run. Temperature does have a positive and significant impact on climatological damages in the long-run, but not in the short-run, while precipitation seems to have no significant impact, although the coefficients are positive in both the short and long-run. Ultimately, the inclusion of these two variables does not to change the significance level of the other variables. Nonetheless, it should be noted that the dependent variable is an aggregated measure of damages and the results could well be different if individual disaster categories were considered. In summary, the main finding from the dynamic analysis is that building up adaptive capacity or effective adaptation is a process taking place over time.

3.3. Examining Determinants across Income Levels

It is critical to examine whether the results from the above specifications are robust across different income levels. In this regard, we use country and year fixed effects along with standard errors clustered by country in a further set of regressions. Results are reported in Table (3). The major message conveyed by the analysis suggests, somewhat similarly to Kellenberg and Mobarak (2008), a bell-shaped relation between damage and per capita income, or, differently said, evidence of insufficient adaptive capacity, if not maladaptation, (at) in low income (levels) countries and efficient “strong” adaptive capacity (at) in high income (levels) countries. The GDP per capita elasticities for the low income countries are indeed positive and larger than one (ranging from 1.701 to 1.960). This could be interpreted as the dominance, at low per-capita income levels, of the “assets-at-risk” or “exposure” effects over adaptive capacity. Accordingly, increasing GDP raises vulnerability. At the higher income levels, the relation reverses: per capita GDP coefficient is larger than one, but negative. Thus more GDP reduces damages highlighting that with development more resources are available for investment in resilient infrastructure and disaster preparedness, the factors most likely influencing adaptive capacity, eventually overcoming the “assets-at-risk” effect.

Table 3: Regressions across Income Levels

Income Range	< $2,500	$5,000	$10,000	$10,000 - $15,000	$15,000 - $25,000	$25,000 >
Variables	**Dependent Variable: Log of Damages**					
Log of GDP per capita	1.960***	1.832*	1.701*	1.285*	-1.244***	-1.982*
	(-0.311)	(-1.099)	(-0.98)	(-0.682)	(-0.139)	(-1.087)
Log of Population Density	0.0625*	0.0671**	0.0751***	0.0797***	0.109	0.554***
	(-0.032)	(-0.029)	(-0.026)	(-0.027)	(-0.161)	(-0.195)
Govt. Exp./GDP	0.188***	0.185***	0.065	0.0273***	0.0377***	0.0602
	(-0.01)	(-0.015)	(-0.046)	(-0.004)	(-0.004)	(-0.150)
Risk	0.880**	0.814**	0.209**	0.821**	3.896**	4.466*
	(-0.386)	(-0.351)	(-0.101)	(-0.387)	(-1.912)	(-2.552)
Agriculture Sector/GDP (%)	0.002	0.004	0.004	0.002	0.011	-0.009
	(0.013)	(0.007)	(0.007)	(0.007)	(0.019)	(0.008)
Openness	-0.234**	-0.301**	-0.31**	-0.442*	-0.218	-0.671*
	(-0.112)	(-0.121)	(-0.123)	(-0.263)	(-0.375)	(-0..358)
Polity	-0.029*	-0.034*	-0.057*	-0.022*	-0.011*	-0.347*
	(-0.016)	-(0.020)	(-0.031)	(-0.013)	(-0.009)	(-0.202)
Constant	7.319	6.04	4.026	2.22	-5.296	21.06
	(-8.205)	(-5.440)	(-5.250)	(-8.703)	(-23.61)	(-22.94)
Observations	331	703	499	106	103	168
Number of Countries	49	77	97	18	16	29

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The analysis by income bins also confirms that larger shares of government expenditure on GDP have a positive relationship with damages. Interestingly, this is not a characteristic of low income countries (even though the related coefficient is considerably higher for particularly low income countries) but a generalized outcome. This result provides some evidence that larger public intervention in the economy may introduce inefficiency also in the action against disaster related damages.

The risk variable is positive and statistically significant for all the income bins; suggesting that the higher the ratio of those killed to those affected, the greater the impact on climate damages for countries. This is particularly troublesome for relatively poorer countries which have larger population exposed to natural disasters. It is worth recalling that in Table 2 the coefficient for this variable was not statistically significant. One particular reason for this could be the fact that we have fewer observations in the regressions segmented by income class which could be influencing the standard errors. The coefficients for the agricultural share of GDP are also no longer statistically significant.

Increased openness seems to reduce damages from climate disasters across all income levels, further reiterating that increased integration with international trade can be an important damage smoothing component. Estimated results also show that regimes with more democratic qualities have a negative impact on damages, with the effect greater in countries with relatively higher income.

3.4. Granger Causality

The analysis conducted in the previous sections highlights indirectly that development, measured by per capita GDP is a driver of adaptive capacity measured by lower damages at least in developed regions. In this section we dig deeper in this relationship. As already noted, it can be argued that the causal relationship between GDP per capita and climate related damages is bidirectional; i.e. damages could determine subsequent income or income could determine subsequent damages. It is also possible to have no interdependency between these two variables.

We test explicitly this link verifying whether per capita GDP Granger causes (lower) damages, if it does then there is further evidence of adaptation. In this case we are not assuming the exogeneity or endogeneity of the underlying variables *a priori*. GDP per capita Granger causes climate related damages if the lagged GDP per capita helps forecast climate related damages. The standard Granger causality test for time series data is not applicable in the case of panel data and needs to be constructed ad hoc. We follow the procedure of Hurlin and Venet, (2001), Hurlin, (2005, 2007) allowing more efficiency, control for individual heterogeneity, a reduction in identification problems, modelling temporal effects without aggregation bias present in time series data, and the usual increased robustness due to the use of panel data (Greene, 2008 and Baltagi, 2005).

The Hurlin heterogeneous non-causality hypothesis (HENC) test, verifies the existence of a causal relation in the Granger sense from the variable *x* to *y* in some or at least one country in the panel even though the relation is no homogenous across the entire panel.

The linear panel data model can be written as:

$$y_{it} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{it-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{it-k} + \epsilon_{it} \quad (5)$$

Where $\gamma_i^{(k)}$ and $\beta_i^{(k)}$ are various coefficients of y_{it-k} and x_{it-k} for country *i*.

We test the causal patterns for four income groups and the coefficients of each group are tested against the null hypothesis of zero causality i.e. $\beta=0$. The F_{HENC} test statistic in practice amounts to build an *F*-test where the sum of squared residuals (*SSR*) from this restricted regression ($SSR2_{ij}$) is then compared to those from the unrestricted model (SSR_1);

$$F_{HENC} = \frac{(SSR_{2,j} - SSR_1)/(n_{nc}p)}{SSR_1/[NT - N(1+p) - n_c p]} \quad (6)$$

In (6) n_{nc} is the subset of countries for which β is restricted to zero, while n_c is the subset of countries for which β is not restricted to zero, N is the number of countries, p is the number of lags, and T is the number of time periods.

A significant F_{HENC} test statistic allows for the rejection of the hypothesis for sub-group j, suggesting that x Granger causes y for that particular subgroup of countries. Thus, if the null is accepted, the variable x does not Granger cause the variable y for all the selected units of the panel. The test however requires the variables to be covariance-stationary. Accordingly, table (4) shows first the panel unit root test results of GDP per capita and climate related damages. A Fisher type test for unbalanced panel suggests that both the log transformed GDP per capita and climate damages are non-stationary in levels but stationary when first differences were taken.

Table 4: Panel Unit Root Tests for Key Variables

Variables	**Fisher Unit Root Test**
Log of Damages	3.549
	(-0.995)
Log of GDP per capita	4.184
	(-0.999)
Lagged Log of Damages	-10.148
	0.000
Lagged Log of GDP per capita	-14.523
	0.000

Note: p-value in parentheses

Hence, we differenced the data for this purpose. Then, in order to conduct the panel Granger non-causality test by Hurlin (2004 and 2005), the requirement is $T_i > 5 + 2K$ (T_i being the time span for country i and K represents the autoregressive lag orders). The panels in our dataset are often relatively short, which limits the degrees of freedom. As a result the analysis is based on $K = 1$. Table (5) shows the results from the panel Granger non-causality test between the first-differences of log of GDP per capita and log of climate damages.

Table 5: Panel Granger Causality Tests: GDP per capita and Climate Damages with Non-stationarity Correction

Panel	*GDP → Damages*	*Damages → GDP*
All countries	0.515	0.596
<$2,500	2.406**	1.365
<$5,000	2.354*	1.248
$15,000 - $25,000	-1.223	0.986
$25,000-$35,000	- 1.301	0.898

Note: The panel Granger homogeneous non-causality (HENC) null hypothesis is *No Granger Causality*. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

We find no evidence of changes in GDP per capita Granger causing higher climate damages for the entire panel. However, for countries with GDP per capita below $5,000 increasing GDP per capita seems to Granger-cause higher climate related damages. In other words, for countries at the earlier stage of development, GDP per capita is a driver (in a Granger sense) of damages (and not vice versa). However, the link goes in the opposite direction that one would expect, as growth brings about more damages. This is further evidence of maladaptation or of increased disaster vulnerability at earlier stages of economic development which is brought about by more assets (and population) at risk not yet compensated by sufficient investment in vulnerability reduction. Echoing one of the theoretical justifications of the Environmental Kuznets Curve-like behavior (see e.g. Ruttan, 1971; Antle and Heidebrink, 1995), it could be argued that protection against weather related disasters is in a way a superior good which enters societal preferences only after more basic needs are fulfilled. For the panel related with income above $15,000, the test statistics are negative, but not statistically significant, suggesting that there is no evidence of increasing GDP per capita Granger causing a reduction in climate related damages. While our regression results suggest that higher income countries are better at improving their adaptive capacity over time, this may not be enough to significantly reduce their monetary damages due to climatological disasters. None of the test statistics in column 2 are statistically significant, suggesting that higher damages do not Granger cause the GDP per capita.

4. Conclusions

In this paper we tried to detect the existence of ongoing adaptation or of the working of adaptive capacity against climate related damages examining a panel combining climate disaster, socioeconomic, and climatic data between 1980 and 2012 for 104 countries. When the analysis is conducted over the entire data set, our results provide evidence of adaptation witnessed by a statistically significant per capita GDP and population density as explanatory of disaster related losses in both the short and the long run.

More specifically, our results suggest that as the income of a country increases, damages from climate related disasters increase, but less than proportionately. We call this, adaptation in a “weak” form. We also find some evidence of maladaptation in the short-run. This could highlight either the fact that increase in damages in the last few decades may have been driven by greater development and more assets being at risk or that adaptation needs some time to exert its effects (Pielke et al., 2008).

Splitting the sample by income bins we are able to offer a richer characterization of adaptation trends. Namely: higher income countries feature adaptation in a “strong” form, i.e. losses are decreasing with per capita GDP. On the contrary, in lower income countries, damages increase more than proportionally with per capita GDP. This provides empirical evidence that in earlier phases of development more “assets-at-risk” tend to prevail over adaptive capacity, increasing vulnerability to climate change. At the higher income levels more resources are available to and likely preferences shift toward, building climate change/disaster resilience. This induces eventually adaptive capacity overcoming the “assets-at-risk” effect. Confirming earlier literature results we also show that regimes with more democratic qualities and trade openness are more successful in adaptation and that countries with larger agriculture sector are more exposed. Finally, developing a panel data Granger causality test, we provide evidence that increasing GDP per capita Granger causes higher climate related damages in lower, but not in higher income countries. This is a further support to the intuition that at earlier stages of economic development more assets become at risk without being sufficiently compensated by investment to reduce vulnerability. This can induce higher economic losses or maladaptation. However, the causalities are not bi-directional, - higher damages do not have a statistically significant impact on GDP per capita. This has an immediate policy implication; development per se is not sufficient to grant (climate change) disaster resilience, but adaptive capacity needs proactive investment to be improved. This applies particularly to low income countries which may face an increasing vulnerability to climate change impacts as one of the undesired effects of “ungoverned” development. Supporting adaptation in lower income countries thus becomes a further means to channel their development towards a more sustainable path.

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