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COMMENT

Comment on 'High-income does not protect against hurricane losses'

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Abstract

Geiger *et al* (*Environ. Res. Lett.* 2016 **11** 084012) employ two functional relationships to characterize hurricane damage in the USA—either based on GDP (one exponent) or on per capita GDP and population (two exponents). From the Akaike Information Criterion the authors cannot reject the former kind in favor of the latter. The different approaches, however, lead to divergent projections of future hurricane losses. In this comment, we argue that there is no rigorous evidence in [1] to give preference to one or the other approach, and the conclusion that high-income does not protect against hurricane losses needs to be revisited. As a perspective, it needs to be mentioned that the previously published relationship between GDP and population could unify both approaches.

Damage functions translate the (physical) magnitude of a natural hazard into a (monetary) damage and commonly have the form

$$L = Af(v) \tag{1}$$

where L is the damage loss, A the maximum potential loss, e.g. capital stock, and $f(v) = L/A$ the relative damage as a function of the magnitude v, e.g. maximum wind speed or other drivers [2, 3]. One distinguishes between *micro*- and *macro*-scale damage functions [4, 5] which relate to the *local* and *global form* used by the authors of [1]. For $f(v)$ different functions including power-law and exponential forms have been studied [6, 7]. In contrast, data on A is rarely available. In [1] the authors explore GDP, per capita GDP, or population as proxies for A. Specifically, two forms are employed, i.e.

$$\text{type 1}: \; A \sim G^{\beta_{\mathrm{GDP}}} \tag{2}$$

$$\text{type 2}: \; A \sim (G/P)^{\beta_{\mathrm{GDPpc}}} P^{\beta_{\mathrm{POP}}}, \tag{3}$$

where G is GDP, P is population, and β are three exponents obtained from fitting.

The authors down-scale GDP according to the population density [1] so that equation (2) can be rewritten as

$$A \sim ((G/P)P)^{\beta_{\mathrm{GDP}}} \tag{4}$$

$$A \sim (G/P)^{\beta_{\mathrm{GDP}}} P^{\beta_{\mathrm{GDP}}}. \tag{5}$$

Thus, comparing equations (3) and (5), one can see that the two models differ only in the number of exponents. However, those exponents are not equally well supported by the data. Strikingly, the per capita GDP extends over less than one order of magnitude (factor ≈ 4), which makes a power-law questionable, while GDP and population extend over five and four orders of magnitude, respectively (figure 3 in [1]).

The question whether or not the goodness of fit justifies the additional parameter in case of equation (3) is answered by the authors themselves.

> Based on the Akaike Information Criterion [...], the gain in predictive quality does not only result from inclusion of an additional parameter [...]. This difference might not be sufficient to reject basic models of type 1 in favor of models of type 2.

However, employing future projections the authors find that the loss estimates of both models differ by a factor between 2.7 and 4.8 based on the SSP2 scenario, and the difference is even larger across the various SSP scenarios. Relative to the national

GDP the projected loss diverges, i.e. strongly increasing in case of equation (3) and slightly decreasing in case of equation (2). As emphasized by the authors, this divergence exceeds any other source of variability in their model chain.

If, yet, the models perform equally well but lead to completely different results, the question needs to be raised how well hurricane damage can be projected at all. The author's conclusion that *high-income does not protect against hurricane losses* needs to be revisited since it is inferred from only one of two conflicting results. In fact, the analysis [1] illustrates the overall limited predictability of hurricane damage. Deviations of the modeled losses compared to the measured ones easily exceed two orders of magnitude (figure 2 in [1]). If one wants to predict the potential loss of individual hurricanes, then this uncertainty ought to be propagated from model calibration to projections.

Another, more technical, issue is the GDP data (reference [23] in [1]). BEA makes a cautionary note 'There is a discontinuity in the GDP-by-state time series at 1997, where the data change from SIC industry definitions to NAICS industry definitions. ... Users of GDP by state are strongly cautioned against appending the two data series in an attempt to construct a single time series for 1963 to 2015.' The authors of [1] did not clarify how they dealt with this issue. If not addressed adequately, such data inconsistencies may obscure true model performance and could be one reason for the apparent indistinguishability of the two diverging models.

Last but not least, we would like to add that power-law correlations have been reported between urban GDP and urban population at a given year [8], i.e.

$$G \sim P^{\beta} \quad \text{with} \quad \beta \approx 1.15. \tag{6}$$

This relation between GDP and population could unify the two models proposed in [1], i.e.

$$\beta_{\mathrm{POP}} = \beta(\beta_{\mathrm{GDP}} - \beta_{\mathrm{GDPpc}}) + \beta_{\mathrm{GDPpc}}. \tag{7}$$

The special case $\beta = 1$ leads to $\beta_{\mathrm{POP}} = \beta_{\mathrm{GDP}}$ and equivalence of both models. Using the estimated exponents of [1], we find that the root mean square difference between the left and right side of equation (7) is minimal for $\beta \simeq 1.04$. Equation (7) opens a relevant research perspective since for β values close to 1, G/P is approximately constant, β_{GDPpc} not defined, and projections from equations (2) and (3) should converge.

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