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Geography, Depreciation, and Growth†

By Solomon M. Hsiang and Amir S. Jina*

Any visit to the seashore will confirm that it is more difficult to build a large sandcastle if one locates the project too near the lapping waves of the ocean. The sandcastle may grow well initially, but eventually a rogue wave washes out some portion of the progress. It may be possible for the sandcastle to grow on net, so long as investment in building outpaces losses to the waves, but it must be true that identical building effort would lead to a larger castle were construction sited on a portion of the beach further from the waves.

Beach-goers face depreciation of sandcastle investments by waves, with an average rate of depreciation that is influenced by their location on the beach. We point out here that similar dynamics apply to capital accumulation, and thereby economic growth, which faces average rates of depreciation that differ by geography.

It has been previously proposed that geography influences economic growth for many reasons. For example, geography may affect labor productivity via health, and trade costs via ruggedness and landlockedness (Gallup, Sachs, and Mellinger 1999); geography affected agricultural productivity during early stages of development which may have enduring influence (Nordhaus 2006; Hornbeck 2012); or geographic conditions could influence the nature of persistent economic and political institutions (Acemoglu, Johnson, and Robinson 2002; Rodrik, Subramanian, and Trebbi 2004; Dell 2010). Yet to our knowledge, prior work has neither suggested nor documented that depreciation varies by location, and thus its potential role in influencing the wealth of nations has not been considered nor explored.

Previous analyses of comparative development seem to have sidestepped the question of location-dependent depreciation out of necessity because data on depreciation were unavailable. For example, seminal work by (Mankiw, Romer, and Weil 1992) stated

> *We assume that [depreciation rates] δ are constant across countries.…[T]here is neither any strong reason to expect depreciation rates to vary greatly across countries, nor are there any data that would allow us to estimate country-specific depreciation rates.*

We continue to lack generally comprehensive measures of capital depreciation, however, the construction of new location-specific measures of tropical cyclone exposure (Hsiang 2010) enables us to consider the potential impact of this single source of capital depreciation. Tropical cyclones—henceforth, "cyclones"—are the class of destructive storms that include "tropical storms," "hurricanes," "typhoons," and "cyclones"—all of which are the same physical phenomena but differ in name based on their location and intensity.

To consider how cyclones affect local rates of depreciation, we first point out that depreciation rates may change across sequential moments in time, holding a location fixed. In the beach-goers example above, there may be moments with no depreciation of a sandcastle (when no waves are near) and there may be later brief moments of rapid depreciation (when a wave is splashing against the sandcastle). Similarly, depreciation of capital accelerates dramatically while it is exposed to a cyclone, which may damage large portions of buildings, roadways, farmland, and other durable assets that depreciate much more gradually at other moments in time. We think most readers will be accustomed to thinking of depreciation as a slow process of capital degradation that does not vary with time, such as an iron bridge rusting gradually. To

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those readers we note that these slow processes also vary over time: the instantaneous rate at which a bridge rusts may change dramatically depending on whether it is daytime, raining, or humid—however, because the process is so slow in absolute terms we have more difficulty discerning these fluctuations with the naked eye.

For a unit of capital k_x at location x that is exposed to a time-varying depreciation rate $\delta_x(t)$, we are generally interested in the average "sandcastle depreciation rate" between time s_1 and s_2:

$$(1) \qquad \overline{\delta}_x \approx \frac{1}{s_2 - s_1} \int_{s_1}^{s_2} \delta_x(t)\, dt.$$

It is this average rate that should affect capital growth per capita, which in a Solow growth model is

$$(2) \qquad \frac{\dot{k}_x}{k_x} = \frac{I_x}{k_x} - \overline{\delta}_x - n_x - g_x,$$

where it is clear that changes in location-specific depreciation should affect per capita capital accumulation similarly to changes in either population growth n_x or technology growth g_x. I_x is investment.

Anttila-Hughes and Hsiang (2011) combine estimates of household cyclone exposure from the Limited Information Cyclone Reconstruction and Integration for Climate and Economics (LICRICE) model with Family Income and Expenditures surveys to estimate how exposure to cyclones alters household assets in the Philippines. They find that higher exposure to cyclones in the prior year increases the likelihood that a household is "conspicuously missing" otherwise durable assets, such as strong roofs, walls, or refrigerators. They interpret this finding as evidence that a fraction of assets are destroyed during cyclone events and characterize the probability of loss averaged across 14 types of assets as

$$(3) \qquad \hat{\delta}_x^C(t) = -0.00069 \cdot C_x(t),$$

where $C_x(t)$ is the area-average maximum cyclone wind speed experienced by province x in year t, measured in meters per second (m/s). We denote the component of total depreciation attributed to cyclones $\hat{\delta}_x^C$ to distinguish it from

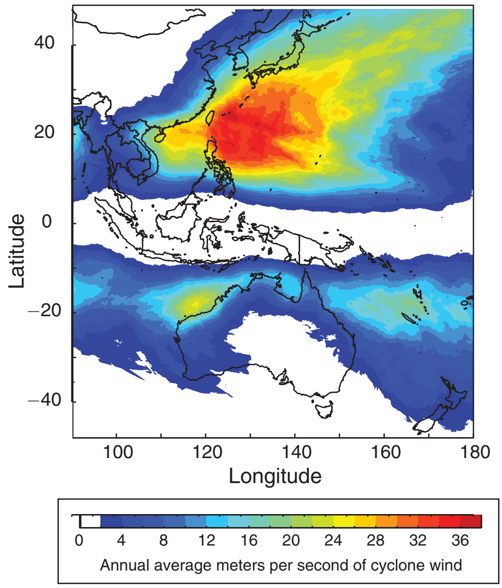

Figure 1. Annual Average Tropical Cyclone Windspeeds from 1950–2008 in the Western Tropical Pacific

other types of depreciation that may also affect these assets. Given an average exposure of 16.9 m/s in their sample, the authors estimate that this portfolio of assets depreciates roughly 1.2 percent per year on average due to cyclone exposure. This conclusion is broadly consistent with results from Hsiang and Narita (2012) who estimate country-level damage as a fraction of GDP using LICRICE, but those results cannot be used to estimate depreciation rates since the exposed capital stock is unknown. To our knowledge, no other study estimates any version of $\hat{\delta}_x^C$, so we rely on equation (3) as our current best estimate.

In Hsiang and Jina (2014) we extended LICRICE to all countries for roughly 6,700 cyclones observed globally during 1950–2008. Using these data, we ask whether geographic heterogeneity in cyclone-driven depreciation $\overline{\delta}^C$ is associated with lower average growth rates, as predicted by a Solow growth model and illustrated in equation (2). As shown by the west Pacific in Figure 1, the distribution of average cyclone exposure is heterogeneous across locations. This heterogeneity is caused by differences in where cyclones are formed—usually the tropical oceans just north or south of the equator—and the wind patterns that drive

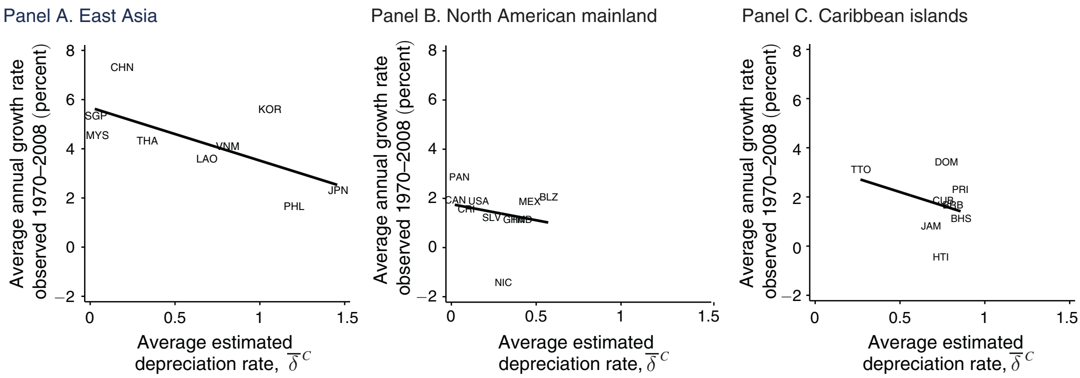

FIGURE 2. AVERAGE GROWTH RATE VERSUS AVERAGE ESTIMATED DEPRECIATION RATE FOR THREE REGIONS

Note: Taiwan omitted because it is an extreme outlier.

these storms toward specific locations more frequently than others. These differences in average exposure can be striking—for example Singapore is almost never struck by storms that either travel north or south of it, while the northern Philippines are exposed to maximal winds over 30 m/s on average per year. Combining equations (1) and (3), this should generate a difference in $\hat{\overline{\delta}}_x^C$ for Singapore and the northern Philippines of roughly 2.1 percent per year. Integrated over multiple years, differences this large may have dramatic effects on the growth rate of wealth, ceteris paribus.

Here we cannot satisfactorily achieve the ceteris paribus assumption needed to fully identify the effect of $\hat{\overline{\delta}}_x^C$ on the growth rate of capital, however a simple cross-sectional analysis does allow us to consider whether the magnitude of expected effects might reasonably explain observed differences in growth rates between countries. To make such a comparison, we first compute the average long-run rate of growth in GDP per capita for 34 cyclone-affected countries reported in the Penn World Tables (version 7.1) during 1970–2008 (Summers and Heston 1991). To do this, we regress *log GDP per capita* on *year* and record the trend, θ_x, for each country. We then compare these long-run growth rates to average sandcastle depreciation rates due to cyclones by computing $\hat{\overline{\delta}}_x^C$ for each country using equations (1), (3), and annual cyclone data from Hsiang and Jina (2014). Long-run average $\hat{\overline{\delta}}_x^C$ is computed for 1950–2008.

Figure 2 displays the scatterplot of estimated long-run average growth rates $\hat{\theta}_x$ against average predicted cyclone depreciation $\hat{\overline{\delta}}_x^C$ for East Asia, the North American mainland (which includes Central America), and Caribbean islands. In all three cases, higher predicted depreciation is correlated with lower long-run growth rates. The association seems clearest for East Asia, where there is substantial variance in predicted depreciation, and least clear for the Caribbean, where almost all islands are predicted to lose roughly 0.75 percent of assets per year on average to cyclones—except Trinidad and Tobago which faces less than half that risk. The overall slope of the relationship appears similar across these three regions, although the vertical intercept differs, perhaps because countries within each region share numerous geographic, cultural, and other economic attributes that differ across regions and are important for long-run growth.

To assess the overall strength of this association globally, we pool these countries with seven more from South Asia and Oceania and estimate a regression that allows for unobserved regional heterogeneity in growth rates, but assume a global relationship between long-run growth rates and predicted cyclone depreciation. Indexing countries by x and regions by r, we estimate the cross-sectional regression

$$\hat{\theta}_{xr} = \beta \cdot \hat{\overline{\delta}}_{xr}^C + \mu_r + \epsilon_x, \tag{4}$$

TABLE 1—AVERAGE GROWTH RATE (1970–2008) REGRESSED ON PREDICTED AVERAGE CYCLONE DEPRECIATION

	(1)	(2)	(3)	(4)	(5)	(6)
Predicted cyclone depreciation	−2.20***	−2.07***	−1.70	−2.19	−1.31	−2.16**
	[0.75]	[0.79]	[1.51]	[6.14]	[2.36]	[0.88]
Observations	34	27	18	8	10	9
Within-region R^2	0.27	0.26	0.07	0.11	0.05	0.44
East Asia	Yes	Yes				Yes
North America	Yes	Yes	Yes		Yes	
Caribbean islands	Yes	Yes	Yes	Yes		
South Asia	Yes					
Oceania	Yes					

Notes: Regressor is the average cyclone exposure times the marginal effect of cyclone exposure (equation (3) estimated by Anttila-Hughes and Hsiang 2011). Regressand is the average long-run growth rate. Both regressor and regressand are in units of percentage points per year. Models with more than one region in the sample include region fixed effects. Oceania includes AUS, NZL, PNG, and IDN. South Asia includes IND, LKA, and BGD. Bootstrapped standard errors in brackets.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

where μ_r are region fixed effects. We compute bootstrapped standard errors because of our small sample sizes. Table 1 reports estimated regression coefficients $\hat{\beta}$. In the sample pooling all five regions, we estimate that increasing the average predicted cyclone depreciation rate by 1 percentage point (i.e., each asset has an additional 0.01 probability of being lost to a cyclone in each year) is associated with a decline of long-run average growth by 2.2 percentage points per year. In this limited sample of cyclone-exposed countries, the within-region R^2 is 0.27, indicating that our estimate for cyclone depreciation rates predicts a substantial amount of the observed cross-country variation in their average growth rates. It is likely that this estimate suffers from some attenuation bias—since we measure cyclone exposure imperfectly—and probably omitted variables bias as well—since there are important covariates that are correlated with cyclone climate which we do not attempt to account for here. Nonetheless, it is notable that the negative association between $\hat{\hat{\delta}}_x^C$ and $\hat{\theta}_x$ appears independently within different regions with a relatively stable magnitude always near −2 (columns 2–6), although several of the estimates are imprecise and not individually significant.

The Solow model predicts that a regression of long-run capital growth rates on average sandcastle depreciation rates should recover a coefficient of −1 (equation (2)). We do not observe total growth, but a regression of long-run income growth rates on the estimated component of depreciation driven by tropical cyclone exposure consistently recovers a coefficient of roughly −2, although no estimate can reject the hypothesis that the coefficient is −1. This might suggest that the long-run elasticity of income with respect to durable capital is larger than unity, that we underestimate depreciation from cyclones, or that omitted variables that are positively correlated with cyclone exposure also have a negative effect on long-run income growth. We think that all three explanations are likely and the threat of omitted variables bias is sufficient that the exact values retrieved from these regressions should not be interpreted too literally. However, we think that the order of magnitude of these estimates are reasonable and their consistent size in subsamples of data suggests the association is not entirely spurious. This leads us to propose that heterogeneous and geographically-dependent depreciation rates may play an important role in global patterns of economic development.

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