American Economic Review: Papers & Proceedings 2015, 105(5): 257–261
http://dx.doi.org/10.1257/aer.p20151030

Tropical Economics†

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Many economists have observed that wealth is systematically lower in the tropics than elsewhere (Sala-i-Martin 1997; Nordhaus 2006). Determining why this is remains a major puzzle. Leading hypotheses include, inter alia, the tropics' disease burden (Gallup, Sachs, and Mellinger 1999), biota available for domestication (Diamond 1997), distance from trading partners (Frankel and Romer 1999), colonial (Acemoglu, Johnson, and Robinson 2001), and other institutions (Easterly and Levine 2003), average temperature (Nordhaus 2006), distance from sources of technology (McCord and Sachs 2013), and frequency of natural disasters (Hsiang and Jina 2014). In fact, so many factors set the tropics apart that it is now common in cross-sectional analyses to use a country's latitude as a proxy for unobserved tropical determinants, although latitude is never itself considered to have fundamental importance as a "deep parameter."

We point out that latitude may have fundamental economic consequence because it plays a key role in how countries experience geophysical processes that have economic implications. Because the earth is spherical and spins rapidly on its axis, irregular variations of Pacific Ocean temperatures, known as the El Niño-Southern Oscillation (ENSO), have distinctive environmental consequences throughout the tropics. ENSO drives large annual fluctuations in local temperature and rainfall throughout the tropics—which are known to have significant influence on various economic outcomes (Dell, Jones, and Olken 2014; Burke, Hsiang, and Miguel forthcoming)—but it is less influential for other countries because of physical constraints on the atmosphere. The relatively larger environmental volatility caused by ENSO in the tropics has the potential to generate unique costs. Here we demonstrate that ENSO drives year-to-year variations in local weather and agricultural economic activity in the tropics. Crucially, we estimate effects of ENSO while controlling for unobserved time-invariant and trending differences between countries, such that our results explicitly isolate an average within-country effect of ENSO on economic activity using only time-series variation.

I. Why Latitude Matters

A profound linkage between "tropical-ness" and exposure to economically meaningful climate variability results from a difference in how tropical and high-latitude locations (hereafter "temperate,") are affected by the planet's rotation. Figure 1 illustrates the central idea. Imagine drawing two dots on a piece of paper and laying it on the ground at a latitude $L_{tropical}$ near the equator. Place an identical piece of paper on the ground nearer the pole at latitude $L_{temperate}$. To a viewer not on the surface of the earth but fixed in space above the planet (who has the perspective of Figure 1), the dots at $L_{tropical}$ will appear to move in parallel with one another as they complete a full rotation once a day. In contrast, the dots at $L_{temperate}$ appear to rotate around one another once per day such that whichever dot is nearest the viewer is furthest from the viewer 12 hours later.

The relative rotation of dots at $L_{temperate}$ is similarly exhibited by the atmosphere overlying this location, affecting how it behaves at this latitude because its angular momentum must be conserved locally. This imposes an additional constraint on atmospheric motions in temperate regions similar to the way in which the angular momentum of a spinning bicycle wheel constrains its motion and keeps the bicycle upright. Because of this additional constraint, weather

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† Go to http://dx.doi.org/10.1257/aer.p20151030 to visit the article page for additional materials and author disclosure statement(s).

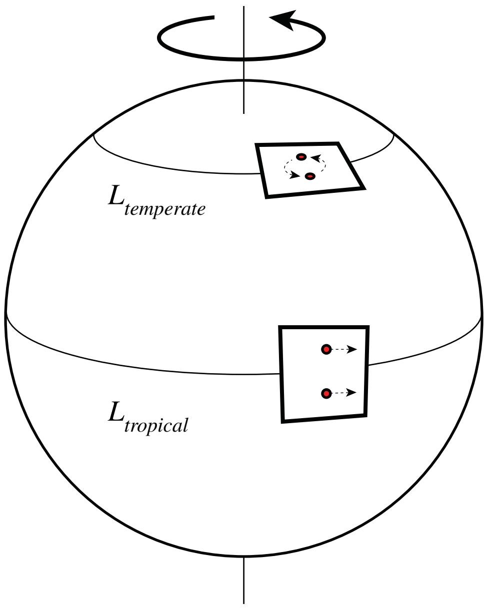

Figure 1. Tropical Latitudes Experience the Earth's Rotation Differently from Temperate Latitudes

patterns at temperate latitudes exhibit organized swirling structures that are experienced on the surface as cold fronts, warm fronts, and distinct high and low pressure systems.

In contrast, the absence of angular momentum at $L_{tropical}$ allows the tropical atmosphere to behave more or less like a bathtub. Similar to when hot water is added to a cold bathtub and mixes quickly, disturbances in the tropical atmosphere are weakly constrained and spread throughout the tropics relatively rapidly. This causes greater uniformity in weather patterns across the tropics. It also implies that large climatological events in one location may systematically affect weather in distant locations. Such is the case in an El Niño event.

II. The El Niño-Southern Oscillation

Roughly every three to seven years, an El Niño event occurs when normal, mutually-reinforcing circulation patterns of the Pacific atmosphere and ocean collapse. This breakdown allows very warm ocean waters that are usually maintained around Indonesia to slosh eastward across the Pacific Ocean, causing the east equatorial Pacific to become substantially warmer than usual and releasing substantial thermal energy into the equatorial atmosphere (Cane and Zebiak 1985). Because the tropical atmosphere is not constrained by relative rotation, the warming of air initiated above the east Pacific is propagated throughout the tropics by a wave in the atmosphere which sweeps the globe, altering climatological conditions throughout the tropics (Chiang and Sobel 2002). An El Niño event typically begins with a warming of the tropical Pacific Ocean during May, which causes warming throughout the entire tropics for roughly a year. In this way, conditions in the tropical Pacific Ocean synchronize annual climatic conditions throughout the tropics, with weaker, and on average opposite, impacts at temperate latitudes. Figure 2 displays an example characteristic pattern of warming experienced around the globe several months after tropical Pacific surface temperatures have peaked.

The irregular switching between hotter and drier "El Niño" conditions and cooler and wetter "La Niña" conditions, with "neutral" conditions somewhere in the middle, is known as the El Niño-Southern Oscillation (ENSO). On annual frequencies, ENSO is a major mode of the global climate system and it is recovered from data as the first principle component of either the atmosphere or ocean. Because of this property, a scalar index of ENSO is considered an important state variable describing the condition of the global climate system at any moment in time. For physical reasons, such an index is well approximated (or defined) by average surface temperatures of equatorial waters in the east Pacific Ocean. For this analysis, we employ the widely used index NINO3.4, defined as average sea surface temperatures in a rectangle defined by 5ºN–5ºS, 170ºW–120ºW (online Appendix Figure 1).

III. Tropical Economic Variability Induced by ENSO

It has been previously demonstrated in numerous contexts that local, idiosyncratic temperature and rainfall variations may induce substantial economic fluctuations (Dell, Jones, and Olken 2014). If ENSO causes large, systematic disturbances in these variables throughout the tropics, it is plausible that this is an important driver of economic volatility in the tropics.

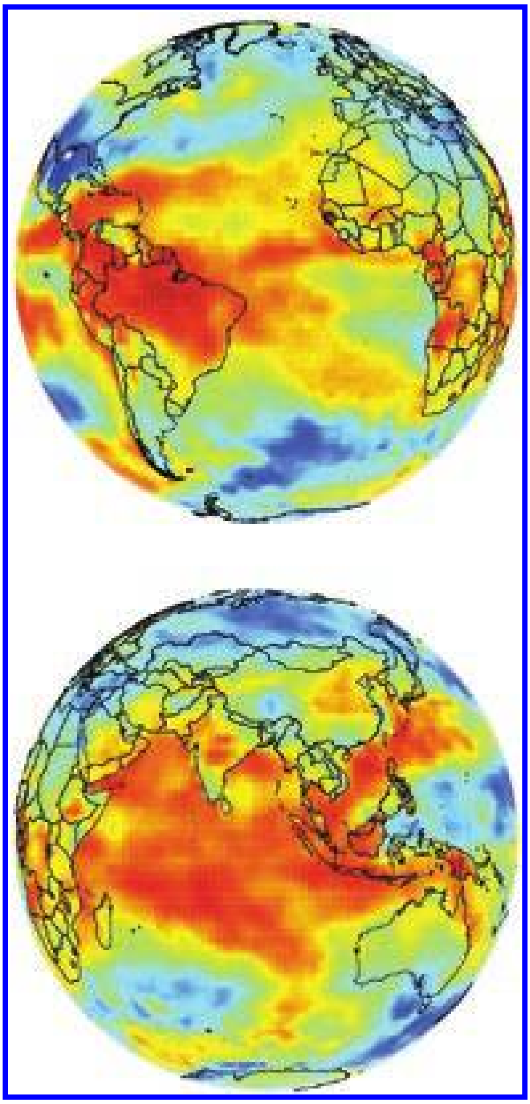

FIGURE 2. CORRELATION BETWEEN DECEMBER SEA SURFACE TEMPERATURE IN THE TROPICAL WEST PACIFIC OCEAN AND TEMPERATURES AT EACH LOCATION FIVE MONTHS LATER

Note: Red indicates strong positive correlation, blue is strong negative correlation.

Source: See Hsiang, Meng, and Cane (2011) for method.

There are spatial and temporal considerations in our country-level panel model. First, we follow the approach developed in Hsiang, Meng, and Cane (2011) to identify the tropical countries whose local temperatures are strongly linked to ENSO and the temperate countries whose local temperatures are weakly affected by ENSO (online Appendix Figure 1 and online Appendix Table 1). Second, also following Hsiang, Meng, and Cane (2011), we measure the dominant state of ENSO in each calendar year by averaging the monthly NINO3.4 index May–December to construct an annual index $ENSO_t$ that can be matched to economic data. Then for outcome Y_{it} in country i, we exploit exogenous year-to-year variation in ENSO to estimate

$$(1) \qquad Y_{it} = \beta_1 ENSO_t + \beta_2 ENSO_{t-1} + \theta_i t + \mu_i + \varepsilon_{it}.$$

θ_i are country-specific trends and μ_i are country fixed effects. β_1 and β_2 capture the contemporaneous and lagged effect of ENSO respectively. Equation (1) is estimated separately for tropical and temperate countries. Because ENSO events span more than a calendar year and, furthermore, could potentially induce temporal displacement of effects, our parameter of interest is $\beta = \beta_1 + \beta_2$. We display β in Table 1 for four outcomes in each tropical and temperate subsample (we report β_1 and β_2 separately in online Appendix Table 2). Finally, we adjust standard errors to account for the potential that disturbances ε_{it} have spatial autocorrelation of arbitrary form within 2,000 km and serial correlation over five years (Conley 1999; Hsiang 2010) (we report results varying these cutoffs in online Appendix Table 3). We also confirm that our linear model provides a reasonable approximation of the data in online Appendix Table 4.

In the first two rows of Table 1, we show that ENSO systematically affects country-level *temperature* and *rainfall* in the tropics (see online Data Appendix). A rise in the ENSO index by +1ºC increases local temperatures in the tropics by +0.27ºC and lowers rainfall by −4.6 mm per month on average (combined over two years). For temperate countries, temperatures actually fall due largely to changes in atmospheric and ocean circulations, but only by half as much, and there is a small but insignificant positive effect on rainfall.

We next examine how *log cereal yields*, *log cereal production*, and *log agricultural value added* respond to ENSO—we presume these effects result mainly from the above temperature and rainfall changes, but there may be additional pathways. A +1ºC increase in the ENSO index

Table 1—ENSO Effects by Region

Outcome	Tropical	Temperate
Temperature (ºC)	0.274	−0.132
	[0.017]***	[0.054]**
Precipitation (mm/month)	−4.636	0.627
	[0.720]***	[0.579]
log cereal yield	−0.020	0.017
	[0.008]***	[0.010]*
log cereal production	−0.035	0.024
	[0.012]***	[0.013]*
log agriculture value added	−0.018	0.016
	[0.005]***	[0.006]***
Observations	2,756	2,043
Countries	78	69

Notes: Each coefficient estimated from a separate country-by-year panel data model with country fixed effects and country-specific trends. Coefficients are β, the combined linear effect of $ENSO_t$ on outcome in year t and in year $t+1$. Sample period is 1961–2009 for all models. Standard errors in brackets are adjusted for spatial (2,000km) and serial (five-years) correlation.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

lowers cereal yields −2 percent, total cereal production −3.5 percent, and agricultural income −1.8 percent on average across the tropics. These effects are highly statistically significant and suggest that rises in prices do not fully compensate countries for declines in agricultural output. For a sense of magnitudes, the ENSO index used as our independent variable ranges from roughly −1.5ºC to +2ºC, with a standard deviation of 0.8ºC. These results suggest that ENSO drives substantial and spatially-coherent fluctuations in agricultural output across the tropics.

We repeat a similar analysis for cereal yields, cereal production, and agricultural income in temperate countries. Consistent with temperature and rainfall changes that are opposite in sign, lower in magnitude, and less statistically significant than corresponding changes in the tropics, we see that cereal yields and production increase in temperate countries when the tropical Pacific warms, albeit with a smaller magnitude that is less significant. Agricultural value added rises and is highly significant, although it is possible that some of this response is linked to general equilibrium price changes, perhaps driven by food shortages in the tropics.

IV. Discussion

We find that agricultural economic activity in the tropics is tightly coupled to the state of ENSO. The absence of relative rotation in the tropical atmosphere allows erratic fluctuations in the Pacific Ocean to increase volatility in the local weather and economies of distant tropical locations. Agricultural economic activity in temperate locations exhibits a reversed response, although the physical linkage is different and the effect is smaller and less statistically significant. If volatility in agricultural production impedes economic growth, the relatively stronger influence of ENSO on the tropics may offer yet another partial explanation for slower historical growth in the tropics.

Our findings have two clear policy implications. First, due to advances in climate modeling, strong ENSO events are now generally predictable up to two years in advance (Chen et al. 2004). Such forecasts offer the potential for improved economic planning in the tropics. Second, despite these advances in prediction, components of ENSO variation remain stochastic, especially for time-horizons longer than 24 months. The asymmetric effects of ENSO on tropical and temperate countries suggest the potential for global risk sharing. In Dingel, Hsiang, and Meng (2015), we explore the extent to which global trade spreads the economic risk generated by ENSO.

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