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Global temperature shocks and real exchange rates☆

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ABSTRACT

We find heterogeneous impulse responses of monthly U.S. dollar (USD) real exchange rates of 76 countries to global temperature shocks. Four years after a positive 1 °C increase in global temperature over its historical average, the Czech Republic currency appreciates by 14.5 percent against the USD while the currency of Burundi depreciates by 4.2 percent. The determinants of response heterogeneity are studied by regressing local projection response coefficients on country characteristics. At the 48 month horizon, a country's currency more likely to depreciate if the country has grown faster, is more dependent on agriculture and tourism.

1. Introduction

This paper studies how monthly U.S. dollar (USD) real exchange rates of 76 countries respond to global temperature shocks. The study employs a two-step empirical methodology. In the first step, we employ local projections (Jordà, 2005) to estimate the real exchange rate response to temperature shocks at various horizons. The local-projection slope coefficients measure the real exchange rate's exposure to a temperature shock. In finance, these estimates would be referred to as real exchange rate 'betas'. In the second step, we regress the local-projection slope coefficients on various country characteristics to study potential explanations for the variation in the estimated impulse responses. This procedure shares similarities with research in finance where average returns are regressed on 'betas' to determine if various risk factors are 'priced' and is particularly close to Lustig and Richmond (2020), who regress the exchange rate's dollar-factor 'beta' on gravity variables.

We highlight two features that distinguish this paper. First, instead of using country- specific temperatures, as is typically done in extant macroeconomic and financial research on climate, we work with a common global temperature factor, which is formed from the cross-section of country temperatures (Bansal et al. (2016) also employ global temperatures). This approach emphasizes the notion that climate change is a global, rather than a country- specific phenomenon, and focuses on differential exposure of exchange rates to common global temperature risks. Since each country is an open economy, not only does that country's own temperature matter for its economic performance, but there are effects on the rest-of-world that circle back through economic linkages to the country in question. These external, spill- over effects can be captured by global temperature shocks. In this dimension, we are following Lustig et al. (2011), who studied heterogeneous exchange rate exposure to common global financial risks. We also emphasize global temperature because it is more systematic and less noisy than country temperature since it is an average across countries[1]. If it is the case that real currency strength represents relative strength in that country's current and future economic fundamentals, a real appreciation caused by a global temperature shock should be reflected in foreign exchange market participants beliefs that the country in question is less adversely affected by the shock than the rest-of-world.

The second feature, is that we focus on estimating and understanding the cross-country heterogeneity of exchange-rate responses to a common climate shock. It is our belief that countries differ in their

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[1] While a country's temperature can be decomposed into a global and idiosyncratic component, we find that the exchange rate response to idiosyncratic temperature shocks to be unsystematic in that they they are unrelated to country characteristics.

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exposure to climate change. Differences in income, geography, and economic structure result in heterogeneity in exposure and capacity for adaptation. If these differences are important, they should be reflected in cross-country differences in real exchange rate responses. To focus on this heterogeneity, we intentionally downplay panel estimation which imposes substantial homogeneity restrictions across individuals (or countries in our case). Instead, our analysis centers on impulse responses estimated from single-equation local projections (Jordà, 2005). Because as we are interested in studying the cross-country variation in responses, estimating the responses from local projections are advantageous because they are less biased and more robust than those from vector autoregressions (Li et al., 2019).

Our estimates do reveal substantial response heterogeneity. In many cases, the impulse responses appear to be permanent. At some horizon (from 1 to 48 months), a positive global temperature shock yields a 5 percent statistically significant appreciation against the USD in 70 percent of the sample countries and a significant depreciation in 61 percent of the countries.[2] Four years after a positive global 1-degree Celsius (1.8-degree Farenheit) temperature shock, the real value of Burundi's currency falls by 4.2 percent against the USD, while the currency of the Czech Republic appreciates by 14.5 percent. At the 48 month horizon, a country's currency more likely to depreciate if the country has grown faster, is more dependent on agriculture and tourism.

Our motivation for studying the effect of climate shocks on the exchange rate is the view that the exchange rate is an asset price that reflects macroeconomic value. To cite Engel (2016),

> 'The foreign exchange rate is one of the few, if not the only, aggregate asset for an economy whose price is readily measurable, so its pricing offers an opportunity to investigate some key predictions of asset pricing theories."

Thus, as a national asset price, the exchange rate is determined by forward-looking market participants who assess effects of today's climate shocks on future economic fundamentals. Since harmful effects generated by current greenhouse gas emissions are realized in the future (Stern, 2007), it would seem to make sense to assess these effects through the lens of asset prices (here, real exchange rates).

The economics that connects climate shocks to the exchange rate is the principle that a strong economy has a strong currency. If temperature shocks cause economic harm, as reported in the empirical damage assessment literature (discussed below), and market participants view a positive shock to be more harmful to a particular country than to the U.S., they will draw down the real value of that country's currency.[3] To illustrate this linkage, we present evidence that following a temperature shock of those countries whose currencies fall, the subsequent consumption growth is more likely to be lower than U.S. consumption growth.

Our paper is part of an empirical literature that assesses the impact of climate shocks on macroeconomic activity and on asset prices. In aggregate asset pricing, Bansal et al. (2016) finds global temperature to have a negative impact on international equity valuations, but they do not investigate response heterogeneity. On the macroeconomics of climate change, the current evidence on exposure heterogeneity and the impact of temperature is mixed. Study- ing the effect of temperature on income growth within the U.S., Hsiang et al. (2017) finds that low-income U.S. counties are more adversely affected than high-income counties. At the state level, Colacito et al. (2019) finds differentiation in U.S. states by latitude, where higher temperatures reduce income growth by more in southern states, but they find the adverse effects of temperature on income growth does not vary by the level of state development. In research using international data, Letta and Tol (2019) and Henseler and Schmuacher (2019) find that total factor productivity of low-income countries are more adversely affected than higher-income countries by higher temperatures. Similarly, Burke et al. (2015), and Dell et al. (2012) find negative effects on GDP growth of temperature but only for low-income countries. In contrast, Kahn et al. (2019) finds no difference in the deleterious effects of temperature between high- and low-income countries. Existing macroeconomic studies generally employ annual data and use local temperature measures. The contrast provided by our paper is that we construct shocks to global temperature factors, use data sampled at monthly intervals, and allow extensive heterogeneity by using single-equation methods.[4]

The remainder of the paper is organized as follows. The next section discusses the data and construction of the global temperature factors. Our first-stage local projection estimates are reported in Section 3. Section 4 contains a robustness analysis. Section 5 presents evidence for an economic mechanism linking relatively bad temperature news for a country's economy to a real currency depreciation. The cross-sectional analysis is presented in Section 6. Section 7 concludes.

2. Real exchange rate and climate data

2.1. Real exchange rate data

Monthly nominal exchange rates and consumer price indices are from *DataStream* which were available for 75 countries plus the Euro.[5] Let S_j be the USD (U.S. dollar) price of currency j, P_0 be U.S. price level, and P_j the price level of country j. Then the real exchange rate, $Q_j = S_j P_j / P_0$, is the real USD price of currency j with $q_j = \ln(Q_j)$. An increase in Q_j means a real appreciation of currency j or a real depreciation of the USD.

2.2. Climate data

We construct population-weighted temperature data for each country and month from 1970 to 2017. Population weighting is standard in the empirical literature on esti- mating the economic damage from temperature. The idea is to place more importance on temperature where people live and production takes place. The global temperature data are from Willmott, Matsuura and Collaborators' Global Climate Resource Pages.[6] These are monthly observations of air temperature (Celsius) on a 0.5-degree by 0.5-degree latitude/longitude grid. We use the shape file from thematicmapping to identify grid points within countries.

The population data are from the Gridded Population of the World database (GPW.v4) of the Center for International Earth Science

[2] The total adds to more than 100 because some exchange rates show a significant appreciation at one horizon and a significant depreciation at another.

[3] Not all economies need be harmed by higher temperature, at least within some range. Stern (2007) notes that positive temperature shocks can potentially be good news for some very high latitude countries. For these countries, some short-run warming can improve crop yields, lower heating bills, and reduce cold-related deaths. See also Nordhaus and Yang (1996) and Tol (2002) who report results from regional integrated assessment models.

[4] Climate research from a finance perspective also includes Bernstein et al. (2019), who estimate the discount on houses subject to flooding due to sea-level rise and Hong et al. (2018) who report that stock prices of food companies respond (but insufficiently so) to country-specific drought trends. In other work, Gorgen et al. (2019) estimate a brown-minus-green risk premium internationally for firms, Balachandrana and Nguyen (2018) show a dependence of firm dividend policy on its carbon risk, while Choi et al. (2019) estimate how local temperature shocks cause people to adjust their portfolios between stocks with high and low climate sensitivities.

[5] Defining the euro area was not straightforward because countries joined at different times. We set the Euro area to be Germany, Belgium, Cyprus, Spain, Finland, France, Ireland, Italy, Luxembourg, Netherlands, Austria, Portugal.

[6] Willmott, Matsuura and Collaborators' data: http://climate.geog.udel.edu/~climate/. Gridded Population database: http://thematicmapping.org.

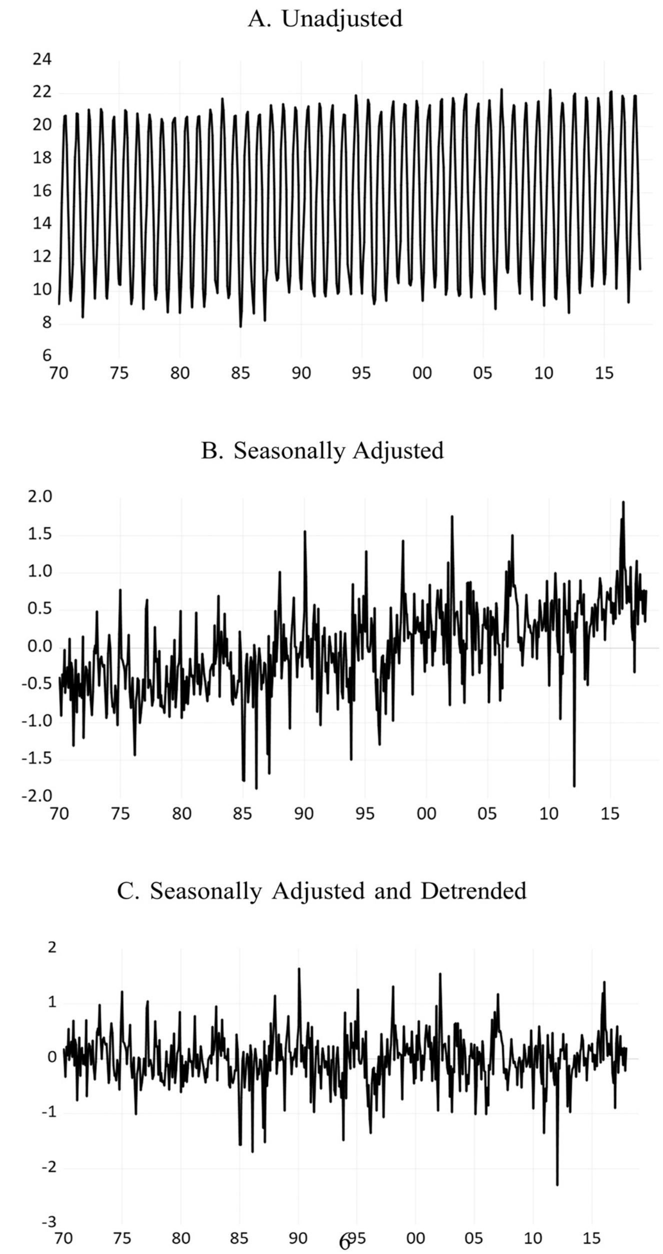

Fig. 1. Global TemperatureUnadjusted Seasonally Adjusted Seasonally Adjusted and Detrended.

Information Network (CIESIN), which includes population counts in 2010 for grid cells matching the grid of the temperature data http:// www. ciesin.org/search.html?q = gridded + population&btnG = Search. We weight the monthly station temperature observations from the grid by population. We then aggregate to the country level by summing the population-weighted temperature points and dividing by the country's total population.

2.3. Temperature shocks

The econometric analysis requires variables to be stationary but global temperatures are trend- ing upwards. We detrend and seasonally adjust the monthly population-weighted country-level temperature readings by regressing on monthly dummy variables and a linear trend. The cross- sectional average of the adjusted country temperatures then serves as our global temperature measure, T_t.

Fig. 1 displays the cross-sectional average of unadjusted country temperatures (Panel A), of seasonally adjusted temperatures (Panel B) and of the adjusted and detrended temperatures (Panel C). Panel B is striking in showing an obvious upward trend in global temperatures starting in the 1980s. The estimated trend coefficient is 0.002 which translates to an increase of 0.24 ^oC per decade during our sample.

To give the global temperature factor more of a shock-like interpretation, we use τ_t, the deviation from the backward-looking average,

$$\tau_t = T_t - (1/t)\Sigma_{j=1}^{t} T_{t-j} \quad (1)$$

The relationship between country i's temperature $T_{i,t}$ temperature and global temperature is given through its decomposition into the common global component and an idiosyncratic component T^o,

$$T_{i,t} = \lambda_i T_t + T^o$$

where λ_i is the loading on the global component. As is well known, the cross-sectional average is approximately the first principal component.[7] We focus on the global temperature component because in preliminary work, the real exchange rate response to idiosyncratic temperature shocks were unsystematic in the sense that they were unrelated to country characteristics (the analysis in Section 6, below). Furthermore, global temperature is more systematic and less noisy than country temperature, since it is a cross-country average. For an open economy, not only would that country's own temperature matter for its economy, but temperature should work indirectly through its effect on the rest-of-world then circling back to the country in question via economic linkages. The exchange rate response is relative not only to the U.S., but also (through the triangular arbitrage condition) to the relevant rest-of-world composite that has trade and financial linkages to the country in question. These external, spill-over effects are efficiently captured by global temperature shocks. Lastly, the temperature decomposition is also useful because global temperature is conceptually closer to climate change, which is a global phenomenon.[8]

3. Local projections

We estimate the response of each country's log real exchange rate (in percent) with local projections (Jordà, 2005). The local projections are the sequence of regressions at monthly horizons $h = 1,., 48$, estimated separately for each exchange rate $j = 1,., 76$,

$$100\,(q_{jt+h} - q_{jt}) = \beta_{jh}\tau_t + X'\,a_{jh} + u_{jt+h}, \quad (2)$$

where X_{jt} is a vector containing the current and three lags of real depreciations as controls and the regression constant. The coefficient of interest is β_{jh}, which measures the percent change in the real exchange rate response from time t to $t + h$ due to the temperature shock at time t.[9] Standard errors are computed by Newey and West (1987).

As there are a large number of impulse response results (48 horizons, 76 exchange rates), the full set of response plots is relegated, which is available upon request. Here, we begin with Table 1, which summarizes the distributional responses across horizons. At each horizon, the table shows the number of negative (-) and positive (+) point estimates, and the number of of those estimates that are significant at the 5 percent level.

[7] Regressing the 1st principal component of the adjusted country temperatures on the cross-sectional average of adjusted temperatures yields a regression $R^2 = 0.709$.

[8] As in Burke et al. (2015), Dell et al. (2012), Colacito et al. (2019), and Hsiang et al. (2017), we assume weak exogeneity of the temperature shocks, so it is not strictly necessary to control for past depreciations. While it is widely believed that climate change has been caused by human activity, we are assuming that the climate shocks we employ are exogenous to the exchange rate. The backward looking average is what Kahn et al. (2019) refer to as the historical norm.

[9] The local-projection coefficients are asymptotically equivalent to the impulse response function from a vector autoregression [Jorda` (2005) and Plagborg-Møller and Wolf (2021)].

Table 1
Local Projection Summary.

Horizon	Negative	Significant Negative	Positive	Significant Positive	Horizon	Negative	Significant Negative	Positive	Significant Positive
1	29	4	47	3	25	46	4	30	2
2	29	4	47	3	26	47	1	29	2
3	33	4	43	4	27	47	2	29	2
4	28	5	48	5	28	47	3	29	2
5	28	4	48	5	29	44	3	32	4
6	40	5	36	6	30	41	2	35	2
7	40	7	36	6	31	41	1	35	6
8	42	7	34	4	32	38	1	38	7
9	36	4	40	5	33	35	1	41	9
10	37	3	39	4	34	35	1	41	12
11	35	3	41	4	35	33	0	43	12
12	37	3	39	5	36	33	0	43	11
13	38	3	38	4	37	31	0	45	11
14	41	2	35	7	38	22	0	54	11
15	37	1	39	9	39	23	0	53	10
16	37	2	39	9	40	24	0	52	8
17	38	2	38	10	41	25	0	51	6
18	38	2	38	9	42	21	0	55	5
19	36	2	40	6	43	18	0	58	8
20	38	2	38	4	44	17	1	59	9
21	39	2	37	4	45	14	1	62	12
22	44	4	32	4	46	10	0	66	15
23	44	4	32	2	47	10	0	66	16
24	45	5	31	3	48	9	0	67	20

Newey and West (1987). Table shows the count of exchange rates for which the local-projection coefficient is negative or positive at some horizon. Significance is at the 5 percent level for a two-sided test.

At short horizons (1-5 months), most responses are positive. Currencies tend to appreciate against the dollar. From horizons 6-21, the count between positive and negative responses are roughly equal. Horizons 22-31 show a preponderance of negative responses. At long horizons (36-48), the vast majority of responses are positive. Substantial and significant response heterogeneity is observed across countries. The temperature shock induces some currencies to appreciate and others to depreciate. Significant appreciations outumber significant deprecia- tions.

The overall statistical significance of these local projection responses is not overwhelming. Because the local projections estimate the exchange rate response relative to the U.S., which range from positive to negative, there will be many responses that are close to zero. It can be no surprise, then, that many of these responses will not display statistical significance. We will address the statistical significance of the responses further in Section 4.

In Fig. 2, we plot individual impulse responses with ± 1.96 standard-error bands for nine countries selected from each income terciles based on 2017 real per capita GDP. The responses for the poor countries shown are a mix of U-shaped (Bangladesh, Kenya, Mozambique, Sierra Leone) and hump-shaped (India, Sudan) responses. For most of the middle income and rich countries shown, real exchange rates show a long-horizon appreciation. The general apprecia- tion of middle-income and rich countries versus the mixed or depreciated response of the poor seems to conform to the conventional wisdom that poor countries (which are generally hot) have the highest exposure to climate. Positive exchange rate responses of middle-income and rich countries indicate that they are less adversely affected by higher temperatures than the U.S.

To summarize, this section has documented evidence that global climate shocks have sig- nificant and heterogeneous effects on real exchange rates across countries. Pooling can achieve higher statistical significance, but our primary interest is in observing individual response het- erogeneity. Before further examination of response heterogeneity, we briefly report results from a robustness analysis.

4. Robustness

We evaluated the sensitivity of the local projections by performing a number of robustness checks. Again, the complete set of results are available upon request reported. Here, we discuss the main findings of this analysis and provide a summary of the robustness analysis in Table 2. The intent of the table is to efficiently summarize the distributional aspects of alternative estimates of the impulse responses with the results reported above. For example, the column labeled (A) reports the raw count of exchange rates that had a significantly negative response to the temperature shock at some horizon. Column labeled (B) shows the analogous counts for significantly positive responses. Column labeled (C) is the count of exchange rates that had a significantly negative and positive responses (at different horizons, obviously). Columns (D)-(F) show these results as proportions of the sample.

Line 1 of Table 2 is the result summary of the local projection analysis from Section 3. As mentioned, these estimates are unlikely to be the result of pure chance, but statistical significance is not overwhelming. Additional statistical significance can be achieved, however, with little distortion in the point estimates by estimating small pseudo-panels. Pseudo-panel estimation proceeds as follows. For each horizon, sort countries by their local-projection betas. Form groups of 5 countries and estimate the panel version of the local projection, Eq. (3), for each group.

$$100\,(q_{jt+h} - q_{jt}) = \beta_h \tau_t + X' a_{jh} + u_{jt+h}, \tag{3}$$

with the homogeneity constraint is imposed only on the global temperature shock slope. We call these pseudo-panels because the group membership can change from one horizon to the next. The pseudo-panel estimation amounts to limited pooling of countries with similar sized local-projection coefficients, primarily for the purpose of standard error reduction. The system is estimated by generalized method of moments (GMM) where the regressors in the individual equations serve as instruments. The GMM standard errors are panel versions of Newey and West (1987) which control for serial correlation induced by overlapping observations.

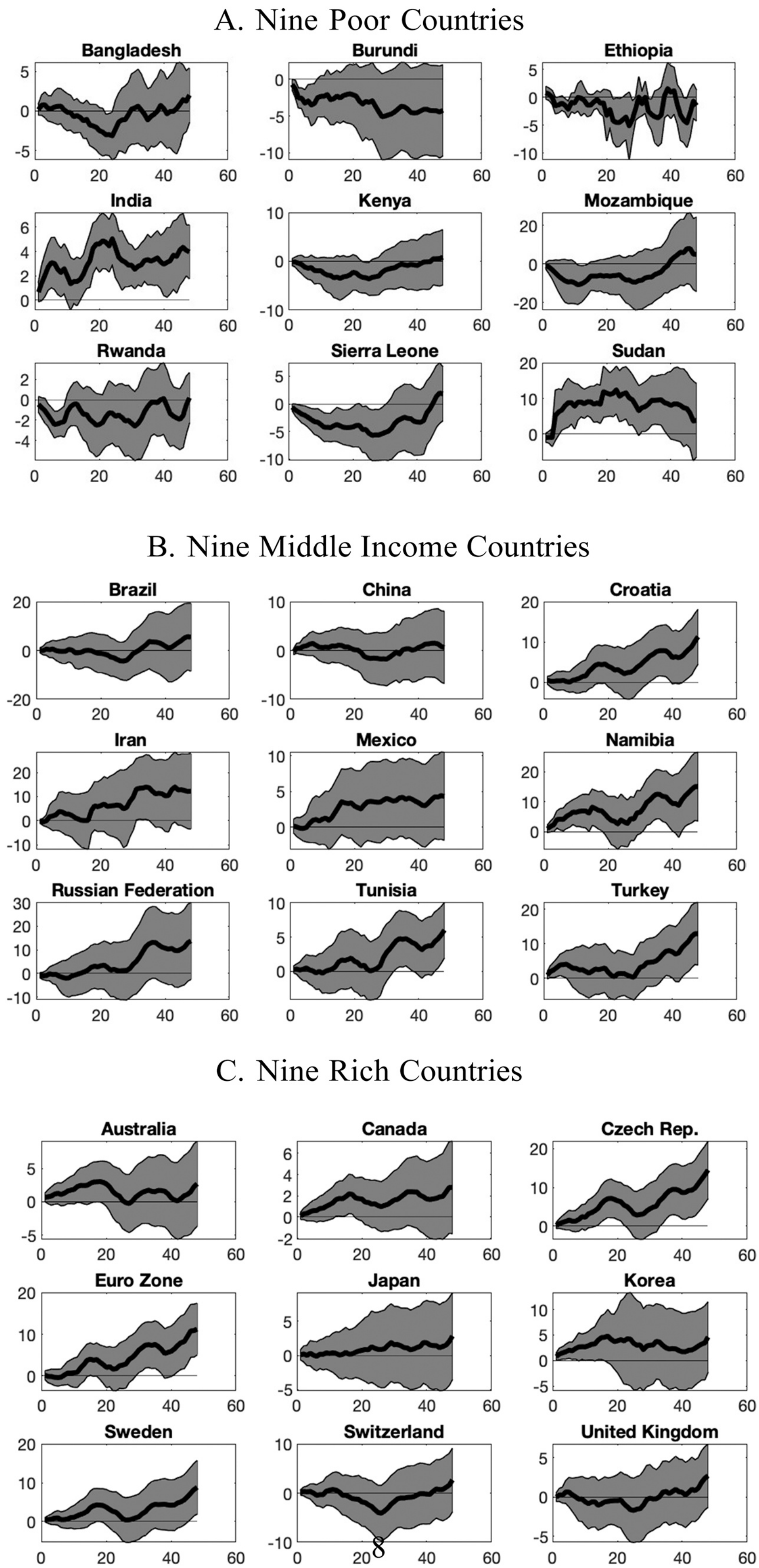

Fig. 2. Impulse Responses to Global Temperature Shocks, Nine Poor Countries, Nine Middle Income Countries, Nine Rich Countries, Note: Shaded area indicates plus and minus 1.96 standard error band.

Table 2
Local Projection Summary for Robustness Checks.

	Counts of Significantly			Proportions of Significantly		
	Negative (A)	Positive (B)	Neg. & Pos. (C)	Negative (D)	Positive (E)	Neg. &Pos. (F)
1. Basic Local Projections	15	28	0	0.197	0.368	0
2. Pseudo Panel	46	53	29	0.605	0.697	0.382
3. Include Lagged Temp.	14	24	0	0.184	0.316	0
4. Include Temp. GARCH	15	28	0	0.197	0.368	0
5. Response to Temp. GARCH	15	45	6	0.197	0.592	0.079
6. Include Interest Differential	13	23	1	0.171	0.303	0.013
7. Include Recession Dummy	9	27	1	0.118	0.355	0.013

Notes. (A): Count of exchange rates displaying a significant negative response at some horizon. (B): Count of exchange rates displaying a significant positive response at some horizon. (C): Count of exchange rates displaying a significant negative response at some horizon and a significant positive response at a different horizon. (D)-(F) convert the counts into sample proportions.

Line 2 of Table 2 shows the pseudo-panel summary. There is a marked increase in statistical significance is achieved whereby the overall proportion of countries for which there is at least one significantly negative estimate increases from 0.197 to 0.605. The pseudo-panel point estimates generally mimic the local-projection single-equation estimates, but the responses and standard errors are more jagged. There is some autocorrelation in the global temperature measure (first-order autocorrelation = 0.29). To check contamination of the impulse responses from omitted variables bias, we include a lag of temperature τ_{t-1} in the local projections. The summary for coefficients on τ_t are shown in line 3. As can be seen, the overall effect on statistical significance is modest, but more importantly, the effect on the point estimates from adding lagged temperature are miniscule.

Apart from the direct, first-moment effects of temperature, one can raise concerns re- garding climate-related uncertainty. There is uncertainty in the climate science, in terms of natural greenhouse gas (GHG) removal (effectiveness of so-called carbon sinks) and carbon sensitivity (temperature change caused by a unit increase in GHGs). Projected future temper- ature changes generated by complicated general circulation models (e.g., the Coupled Model Intercomparison Project [(Eyring et al., 2016))]) show substantial variation across models.[10] There is also uncertainty about the extent of past and future economic damages caused by climate change. The social cost of carbon estimated from integrated assessment models varies considerably depending on how uncertainty and potential climate tipping points are handled.[11]

While a full-fledged investigation into the effects of climate-induced uncertainty on the exchange rate is beyond the scope of this project, we investigate possible bias from omission of a GARCH measure of temperature uncertainty.[12] Here, we estimate a GARCH(1,1) model for τ_t and include the estimated conditional variance in the local projections. The GARCH model is fitted to the residual from $\tau_t = \rho_0 + \rho_1\tau_{t-1} + \epsilon_t$, where $E_{t-1}(\epsilon_t^2) = g_t = \alpha_0 + \alpha_1\epsilon_t^2 + \gamma g_{t-1}$. The GARCH model estimates and a plot of the estimated conditional variance are reported.

Line 4 of the table shows the summary impulse response to temperature shocks with g_t included in the regressions. As can be seen, including the conditional variance of temperature has no substantive effect on the impulse responses to temperature shocks. Plots comparing impulse responses estimated with and without the conditional variance in the local projections show virtually no differences.

Line 5 of the table reports the summary on impulse responses to shocks in the temperature conditional variance. Most countries experience real currency appreciations relative to the dollar in response to shocks in global temperature conditional variance. Apparently, shocks to global temperature variance (uncertainty) is relatively bad news for the United States compared to most of the countries in the sample. These results introduce a second facet of climate on exchange rates through the uncertainty surrounding currently predicted damages and risk assessments due to current emissions. Since asset markets are institutions where risk and uncertainty are priced into traded assets, it is again natural to look to how foreign exchange market participants assess the impact of climate risks and uncertainty on national economies. While it is beyond the scope of this paper, these results suggest there are useful avenues to pursue, but we leave a careful and complete analysis for future work.

Line 6 shows the summary results when the real interest differential is included as a control in the regression. Real interest differentials might be thought of as the default explanatory variable for real depreciations working through interest parity. Interest rate and consumer price data are from IMF *International Financial Statistics* (IFS). Including the real interest differential as a control variable has a very modest effect on the estimated response significance. For most exchange rates, the effect on the point impulse responses are trivial. There are a few exceptions (notably Ecuador, Iran, Korea, Poland), whereby the response has been dampened, but also a number of instances where the response is magnified (Cyprus, Greece, Israel, Kenya, Lithuania, and Latvia).

Finally, we include recession dummies as controls. The recession dummies are based on annual real GDP growth obtained from the IFS. For each country, every month in the calendar year is coded as a recession if real GDP growth that year for the country is negative. Line 7 shows the response summary to temperature shocks when recession dummies are included. The number of significant negative responses declines from 15 to 9 but the number of significant positive responses is reduced only from 28 to 27. In terms of the point estimates, including recession dummies results in dampened responses only in a handful of cases (Croatia, Czech Republic, Ecuador, Poland, and Slovenia), but magnified responses in many more cases (Austria, Belgium, Italy, Lithuania, China, Spain, Netherlands, Ireland, Iceland, Israel, and Portugal).

5. Linking temperature to the real exchange rate

What is the economic mechanism linking the real exchange rate to global temperature shocks? The canonical utility-based exchange rate pricing model under complete markets (sometimes referred to as the stochastic discount factor (SDF) approach to the exchange rate (Lustig & Verdelhan, 2012)) provides one possible story. In this section, we first present this frame- work as an elegant and possible organizing

[10] See also Hsiang and Kopp (2018), Pindyck (2020) and Dietz et al. (2020) on climate science uncertainty.

[11] For example, see Nordhaus (2007), Nordhaus and Yang (1996), Golosov et al. (2014), Cai and Lontzek (2019), Bansal et al. (2016). Barnett et al. (2020) study optimal climate policy decisions under uncertainty. If climate-induced uncertainty causes future the distribution of future consumption growth to be fat-tailed, Weitzman (2009) and Weitzman (2014) shows that the social cost of carbon can be infinite–a result known as the 'Dismal Theorem.'

[12] This was kindly suggested by a referee.

framework for thinking about the temperature exchange rate mechanism. The drawback, however, is the substantial empirical challenge to this framework posed by the data. After documenting some of these challenges, we present an empirically-based argument that links temperature shocks, relative economic responses and real exchange rate responses. Section 4.3 briefly discusses an alternative mechanism, based on real interest parity and a Taylor-rule monetary policy, which implies that good economic news should generate a real appreciation.

5.1. A complete-markets utility-based mechanism

Let there be $n + 1$ countries, indexed by $j = 0, 1,., n,$ where the United States is country 0. Let m_{jt} be the logarithm of country j's stochastic discount factor. Under complete markets, the real dollar depreciation relative to currency j is equal to the difference in log stochastic discount factors (Lustig & Verdelhan, 2012; Backus et al., 2001; Backus & Smith, 1993; Brandt et al., 2006)[13],

$$\Delta q_{jt+1} = m_{jt+1} - m_{0t+1} \tag{4}$$

Note that if there is no heterogeneity in the cross-country stochastic discount factors (in the sense that m_{jt} and m_{0t} are perfectly correlated), the exchange rate will be constant. Because real exchange rates are observed to vary (quite a bit) over time, there must be heterogeneity in the way that discount factors of different countries respond to shocks. This heterogeneity might stem from cross-country differences in income, stage of economic development, geography, and latitude. The heterogeneity of interest in our context is the different ways country j and the U.S. stochastic discount factors are affected by common global temperature shocks τ_t.

Let $c_{jt} = \ln C_{jt}$ be log consumption. If economic agents across countries have identical time-separable, constant relative risk aversion utility,

$$U(C_{jt}) = \frac{e(1-\gamma)c_{jt} - 1}{1 - \nu} \tag{5}$$

where C_{jt} is consumption, and ν is the coefficient of relative risk aversion, then the log stochas- tic discount factor is

$$m_{jt+1} = -\rho - \gamma\Delta c_{jt+1}, \tag{6}$$

where ρ is the subjective rate of time preference. Combining Eqs.(5) and (6), and by the log-linearity of the SDF, we can express the h-horizon real depreciation as

$$q_{jt+h} - q_{jt} = \gamma\left[(c_{0t+h} - c_{0t}) - (c_{jt+h} - c_{jt})\right] \tag{7}$$

A key feature of integrated assessment models (e.g., Nordhaus (2007), Nordhaus and Yang (1996), Golosov et al. (2014), Cai and Lontzek (2019), Bansal et al. (2016)), is the damage function, which maps increased temperature onto reductions in income, consumption, and welfare. Drawing on these studies, we postulate the direct dependence of consumption growth on temperature shocks. If τ_{jt} is country j's temperature shock, projecting consumption growth on τ_{jt} gives,

$$c_{jt+h} - c_{jt} = \delta_{jh}\tau_{jt} + u_{jt+h} + \varphi_{jh}, \tag{8}$$

where u_{jt+h} is the projection error and φ_{jh} is a constant. Next, decompose country-specific temperature τ_{jt}, into orthogonal components consisting of a common global temperature factor τ_t and an idiosyncratic temperature factor τ^o,

$$\tau_{jt} = \lambda_j\tau_t + \tau^o \tag{9}$$

where λ_j is the global temperature factor loading.[14] Substituting (9) and (8) into (4) gives

$$q_{jt+h} - q_{jt} = \beta_{jh}\tau_t + \epsilon_{jt+h} + \mu_{jh} \quad ,(10)$$

where $\beta_{jh} = \gamma\,(\delta_{0h}\lambda_0 - \delta_{jh}\lambda_j)$, $\epsilon_{jt+h} = \gamma(u_{0t+h} - u_{jt+h} + \delta_{0h}\tau^o - \delta_{jh}\tau^o)$ is a composite errorjt term, which is orthogonal to τ_t, and $\mu_{jh} = \gamma\,(\varphi_{0h} - \varphi_{jh})$ is a constant.

Eq.(10) gives the local projections of the exchange rate depreciation on global temperature shocks. A temperature shock is bad news for country j's currency if $\beta_{jh} < 0$ and $\delta_{jh}\lambda_j > \delta_{0h}\lambda_0$. This would be relatively bad economic news for j if the temperature shock causes a temporary contemporaneous relative decline in current consumption c_{jt}, and a relatively higher expected consumption growth rate, Δc_{jt+h}, as future consumption to returns to 'normal.'

The problem with this argument is the empirical failure of Eq. (4) under constant-relative-risk aversion utility–a feature of the data known as the Backus and Smith (1993) puzzle and/or as the consumption real-exchange rate anomaly (Kollmann, 2016). We illustrate this issue with our data by running the regression implied by Eq.(7). We run Eq.(7) using the countries in our sample (subject to consumption data availability). The theory predicts a positive slope $\gamma > 0$.[15]

Histograms of the γ estimates at horizons $1-4$ are shown. Here, we display the point estimates at horizon 4 in Fig. 3. As can be seen, most of the individual point estimates of ν are negative, which is the wrong sign. This is also troubling because risk aversion coefficients typically need to be quite large for asset returns to be consistent with consumption data. Hence, we would expect large positive estimates of γ, but instead we get estimates that are the wrong sign.[16]

5.2. Empirical evidence for the mechanism

Given the empirical challenges to the above framework, we turn to an empirically-based argu- ment that a temperature shock which is relatively bad economic news for country j is also bad news for its currency.

We estimate the relative economic impact of temperature shocks, with local projections of consumption growth, relative to the U.S.,

$$(c_{jt+h} - c_{jt}) - (c_{0t+h} - c_{0t}) = \alpha_{jh}\tau_t + \epsilon_{t+ht} + X'\,d_{jh}, \tag{11}$$

where X_{jt} is a vector containing the scalar 1 for the constant and $\Delta c_{jt} - \Delta c_{0t}$ as a control. An increase in global temperature is relatively bad news for country j if $\alpha_{jh} < 0$. We estimate (11) at horizons $h = 1, 2, 3,$ and 4 years. Histograms of the estimates at each of these horizons, and plots of the full set of impulse responses are relegated. Here in the text, we illustrate the general pattern in Fig. 4, which plots the local projections coefficients α_{j4} at horizon $h = 4$. Interestingly, the estimates are positive for most countries in our sample. The U.S. is more adversely affected by global temperature shocks compared to most countries in our sample. Also, the relative consumption growth local projection coefficients also tend to persist. Relatively good news from increased temperature leads to higher relative growth not just in year 1 but also in years 2, 3, and 4. This persistency may provide a clue as to why the SDF approach doesn't work.

Temperature news doesn't just have a transitory impact on current consumption with future consumption expected to revert back to

[13] Alternatively, the log intertemporal marginal rate of substitution.

[14] An earlier version of our paper explored the role of idiosyncratic temperature shocks, and concluded that they were uninteresting in the sense that exchange rate responses did not systematically vary with country characteristics (the analysis of Section 6 below). Those results align with predictions from the theory of finance, which says that unsystematic risks should not be

(footnote continued)
priced into assets. Consequently, we have dropped the analysis of the idiosyncratic temperatures from the paper.

[15] For these regressions, the real exchange rates are point-sample annualized because the consumption data are annual.

[16] The predicted positive slope is not specific to time-separable power utility. In their two-country long-run risk framework with recursive utility, Colacito, R., & Croce, 2011 find the correlation between the real exchange rate depreciation and home country relative to foreign country consumption growth to be 0.8.

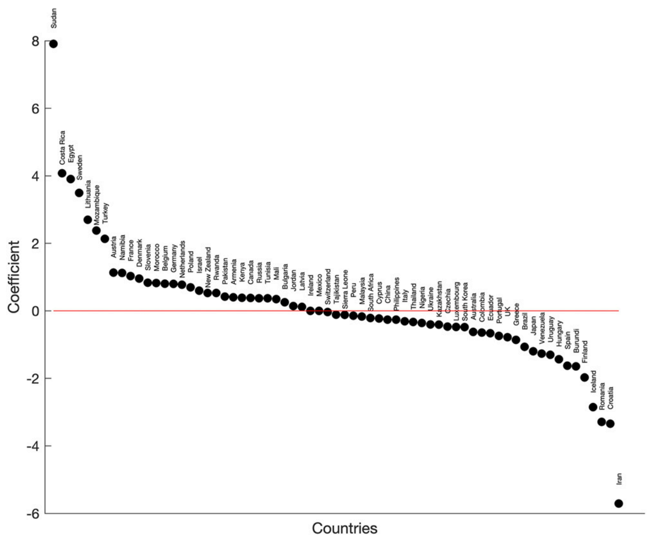

Fig. 3. Point Estimates of ψ from Eq.(7) at Horizon 4 Notes: Slope estimates from regressing $q_{jt+4} - q_{jt}$ on $(c_{0t+4} - c_{0t}) - (c_{jt+4} - c_{jt})$. Horizon measured in years.

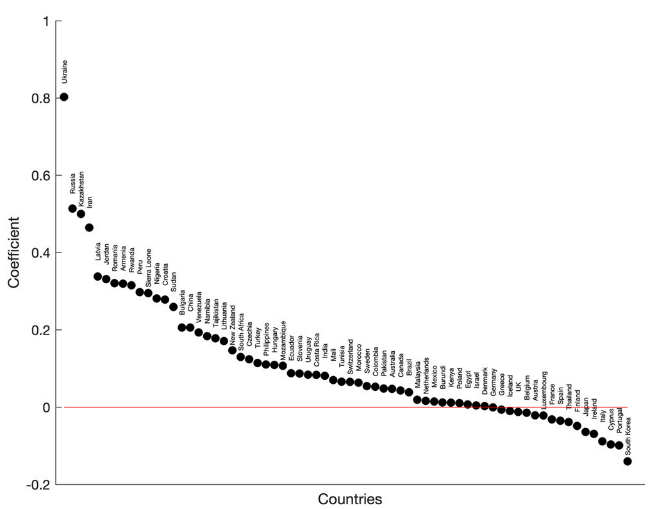

Fig. 4. Relative Consumption Growth Local Projection (Eq. 11) at Horizon 4 Notes: Slope estimates from regressing $(c_{jt+4} - c_{jt}) - (c_{0t+4} - c_{0t})$ on τ_t. Horizon is measured in years.

normal. Bad news about temperature seems to lead to persistently lower consumption growth and persistently lower currency valuation.

If higher temperature is both bad economic news and bad exchange rate news, the α_{jh} from the relative consumption local projections Eq. (11) and the β_{jh} from the exchange rate local projections Eq.(10) should be positively correlated. To investigate whether this is true, for each horizon $h = 1, 2, 3, 4$, we run a cross-sectional regression of the estimated real exchange rate local projection coefficients $\hat{\beta}_{jh}$ on the estimated relative consumption local projection coefficients $\hat{\alpha}_{jh}$,

$$\hat{\beta}jh = \phi_{jh} + b_{jh}\hat{\alpha}_{jh} + e_{jh}, \tag{12}$$

where ϕ_{jh} is the regression constant.[17] The estimation results are shown in Table 3 and Fig. 5. The positive estimates of b_{jh} is consistent with the mechanism whereby relatively bad economic news for country j is associated with a real depreciation of currency j. If $\alpha_{jh} < \alpha_{j'h}$, the temperature news is worse for j than j'. We then also expect a lower valuation of j's currency relative to j', indicated by $\beta_{jh} < \beta_{j'h}$.

[17] The $\hat{\alpha}_{jh}$ are generated regressors which cause OLS estimates of b_{jh} to be biased and standard errors distorted. We correct for bias and size distortion by Meng et al. (2016).

Table 3
Slope Estimates from $\hat{\beta_{jh}} = c_h + b_{jh}\hat{\alpha}_{jh} + e_{jh}$ with Generated Regressor Adjustment.

	1-year	Horizon 2-years	3-years	4-years
Estimate	0.369	0.055	0.750	1.036
T-Ratio	7.035	71.117	9.454	7.065

Meng et al. (2016).

5.3. An alternative mechanism

We briefly mention an alternative mechanism by which good relative economic news leads to real currency appreciation, although it has somewhat fallen out of favor in recent years. This mechanism is based on real interest parity in conjunction with a Taylor-type monetary policy rule for the interest rate (see Engel (2015)). Let the home-U.S. nominal interest rate differential be $\tilde{\imath}_t$. To keep things simple, let both the home country and the U.S. have the same Taylor-rule parameters. Suppressing constants and policy shocks, gives

$$\tilde{\imath}_t = \lambda E_t \tilde{\pi}_{t+1} + \gamma \tilde{y}_t$$

where $\pi\tilde{\pi}_{t+1}$ is home relative to U.S. inflation, $\tilde{y}_t$ is home relative to U.S. output gap, $\lambda > 1$ and $\gamma > 0$. Subtracting expected relative inflation from both sides gives the real interest differential,

$$\tilde{r}_t = (\lambda - 1)E_t \tilde{\pi}_{t+1} + \gamma \tilde{y}_t$$

Under real interest parity, the expected real currency depreciation is equal to the real interest differential,

$$E_t q_{t+1} - q_t = \tilde{r}_t = (\lambda - 1)E_t \tilde{\pi}_{t+1} + \gamma \tilde{y}_t,$$

and upon rearrangement,

$$q_t = (1 - \lambda)E_t \tilde{\pi}_{t+1} - \gamma \tilde{y}_t + E_t q_{t+1} \tag{13}$$

Then solving (13) forward and assuming that $\lim_{j\to\infty} E_t q_{t+j} = q_\infty$ is finite, gives the real ex- change rate in terms of the present value of future inflation and output gap differentials,

$$q_t = E_t\left(\sum_{j=0}^{\infty} (1 - \lambda)\tilde{\pi}_{t+j+1} - \gamma \tilde{y}_{t+j} \right) \tag{14}$$

The home currency appreciates in real terms (q declines) if a temperature shock is good relative news for the output gap and/or if it is good good relative news for inflation (because $(1 - \lambda) < 0$).

6. Analysis of cross-sectional real exchange rate response heterogeneity

The local projection estimates revealed response heterogeneity across countries. The U.S. was affected adversely by global climate shocks than many countries (the appreciators) and to less adversely affected than others (the depreciators). In this section, we study the role that economic structure, stage of development, and investor perceptions might play in explaining the response variation across countries.

This investigation is conducted by regressing the 48 – month horizon local-projection coeffi- cients $\hat{\beta}_{48}$ on a set of country characteristics. We limit the analysis to the 48 – month horizon to give foreign exchange market participants and price-level adjustments four years to assess

the implications of the temperature shock. If X_j is the vector of country j's characteristics and the scalar 1 for the constant, we run the cross-sectional regression

$$\hat{\beta}_{j,48} = X'\theta + u_j, \tag{15}$$

The methodology is closely related to Lustig and Richmond (2020), who regress the exchange rate's base factor 'betas' on 'gravity'

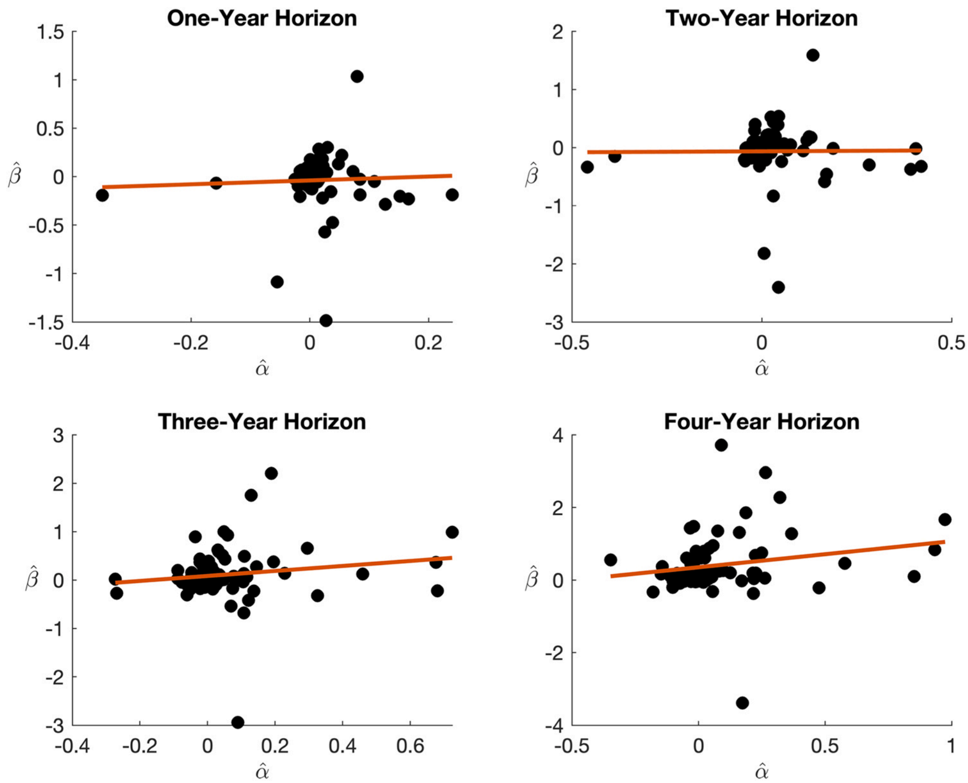

Fig. 5. Scatter Plots of $\hat{\alpha}_{jh}$ and $\hat{\beta}_{jh}$.

variables. There is no generated regressors problem or 'first-stage error' problem in this analysis, because the local projection response is the dependent variable in the regression.

We consider country characteristics that potentially inform about the country's economic exposure to and capacity for adapting to warming. The variables and rationale for including them are as follows.[18]

1. GDPPC – Per capita GDP. The presumption is that richer countries have more resources to devote towards adapting to rising temperatures. Lower-income countries employ tech- nologies that are more labor intensive and for which labor is more exposed to climate (e.g., they tend not to work in air-conditioned offices). Microeconomic studies estimate nega- tive effects of higher temperature on labor productivity. Heal and Park (2016) reviews the empirical literature on the direct effects of high temperatures on labor productivity and concludes that the negative effects are of first-order significance. There are multiple channels linking income to climate exposure, such as adverse effects on health, labor productivity, and possibly reductions in human capital accumulation. Due to resource limitations, lower-income countries are less able to adapt to warming, which leaves them more exposed. Per capita GDP should enter with a positive sign.
2. OPEN – the share of trade to GDP (openness). Trade is measured as the sum of exports and imports. We expect the trade variable to enter with a positive sign. While standard trade theory predicts that increased openness through reductions of trade barriers leads to greater efficiency, more recently, the literature has presented convincing evidence that openness leads to higher economic growth (see Irwin (2019) for a survey of recent work).[19] Furthermore, economies of countries that do more trade may be more diversified, making them more resilient to temperature shocks. The trade share should enter with a positive sign.
3. AGSHR – the share of agriculture in GDP. Macroeconomic exposure to warming through agriculture is ambiguous. From Stern (2007), crop yields may increase initially in the higher latitudes, due to the carbon fertilization effect. For these countries, agricultural productivity may display a hump-shape with respect to temperature–warming initially benefits agriculture but only up to a certain point. However, in tropical regions, warm- ing may have adverse effects on agricultural yield. Climate change also increases the frequency of heatwaves, droughts, and severe floods leaving countries with large agri- cultural sectors to be more exposed to these risks. But physical crop yields are not the only consideration. Agriculture represents a larger share of GDP in lower-income countries and employs a larger share of labor who are directly exposed to the elements. Agricultural share should enter with a negative sign.
4. TOURISM – tourism as a share of exports. Tourism is measured as expenditures by in- ternational visitors. Macroeconomic exposure through tourism is ambiguous. On the one hand, tourist spending on cold-weather related leisure activities, such as alpine skiing, are clearly at risk.[20] Similarly, for countries that are already hot, tourism may decline with additional warming. Alternatively, warming could enhance leisure tourism by extending warm-weather activities. Chan and Wichman (2020), using data from bike-sharing

[18] Per capita GDP data are from the Penn World Tables. The other data on country characteristics are from the World Bank database. The observations are average values for all variables. We omit the U.S., since the exchange rate response is relative to the dollar, and including U.S. variables does not contribute any variation.

[19] Irwin (2019) points out that some of the largest and most important growth accelerations (in Taiwan (1962), Brazil (1967), China (1991), India (1991), and Poland (1991)), seemed to occur around the time of major trade reforms.

[20] See "Climate Change is Killing Alpine Skiing as We Know It," https://www.bloomberg.com/news/articles/2020-01-15/climate-change-is-killing-alpine-skiing-as-we-know-it, and "How Climate Change is Affecting Tourism," https://www.travelpulse.com/news/destinations/how-climate-change-is-affecting-tourism.html.

Table 4
Correlations Amongst Characteristics.

	OPEN	AGSHR	TOURISM	GROWTH	VULN	OILSHR
GDPPC	0.640	-0.637	-0.204	0.220	-0.790	-0.239
OPEN		-0.329	-0.096	0.068	-0.409	-0.223
AGSHR			0.078	-0.224	0.822	0.040
TOURISM				-0.078	0.085	-0.215
GROWTH					-0.143	-0.130
VULN						0.136

pro- grams finds potential gains for outdoor recreation, at least initially, from warming. Ex ante, the sign on tourism is ambiguous.

5. GROWTH–real per capita GDP growth experienced from the first year to the last year in the sample. This is a measure of the country's long-term economic growth. On the one hand, countries that have experienced high sustained growth might be better equipped to deal with climate change. On the other hand, high growth countries are less industrialized and less developed than the rich countries, and have younger populations and higher fertility rates, which could work against their ability to deal with global warming. Ex ante, the sign on long-term growth is ambiguous.
6. VULN–vulnerability index, constructed by the Notre Dame Global Adaptation initia- tive.[21] This variable measures a country's exposure, sensitivity and capacity to adapt to negative effects of climate change. We include it to study whether investors process infor- mation from temperature shocks as being about the physical risk from climate change. Under this mechanism, all else equal, the real exchange rate should depreciate if it is relatively more vulnerable to physical climate risks. Here, foreign exchange market par- ticipants interpret global temperature shocks as news about future climate change which they use to update their beliefs about future climate risk.
7. OILSHR–the oil sector's share of GDP. We included this variable to assess the extent to which foreign exchange market participants interpret temperature shocks to impact transition risk towards a green economy. It's not clear what the sign of the response should be, however. A higher oil share suggests a higher risk of stranded assets from which we might expect a negative response. However, a temperature shock could signal increased urgency to extract the oil, at least over the time-frame of our analysis.

Table 4 shows the correlation matrix of the country characteristics. The well-known nega- tive correlation between per capita GDP and temperature shows up prominently. The negative (positive) correlation between agricultural share and real GDP illustrates how agriculture plays a larger economic role in poor, hot countries nearer to the equator. Rich countries are seen to be more open to trade. Export earnings from tourism and long-term growth are not highly correlated with the other characteristics.

Table 5 splits cross-sectional means of country characteristics across broad country classi- fications. Hot and cold, poor and rich, classified by being above or below the median value. As can be seen, poor countries tend to be hotter. Hot and poor countries do less trade and do more agriculture. Tourism plays a larger role in export earnings for hot countries, but the differences between rich and poor countries is less pronounced. Poor countries are more vulnerable (according to VULN) and more reliant on oil as an income source.

Look at Table 6 Column 'ALL'. We obtain the expected signs on openness, agricultural share, tourism, and vulnerability. Of these, only openness is significant. The negative sign on er capita GDP and long-term growth is unexpected, but is consistent with estimates reported by Berg et al. (2022) who study on GDP growth response to temperature shocks. Country currencies tend to appreciate after a global

[21] https://gain.nd.edu/our-work/country-index/download-data/

Table 5
Mean Country Characteristics by Broad Classifications.

	Hot	Cold	Poor	Rich
GDPPC	11.128	36.214	7.997	39.263
OPEN	63.356	102.642	61.107	104.832
AGSHR	15.343	3.868	16.528	2.714
TOURISM	63.356	102.642	61.107	104.832
GROWTH	1.014	1.156	0.973	1.195
VULN	0.471	0.347	0.477	0.341
OILSHR	3.447	1.351	3.972	0.855

Notes: Ratios stated in percent. GDP per capita divided by 1000.

temperature shock if they are poorer, more open, less reliant on tourism, and have experienced less rapid growth. The coefficients on oil's share and agriculture's share are far from significant.

Looking at how the explanatory power of country characteristics differs across broad coun- try classifications, we see the negative coefficient on income is driven by cold and rich countries. The positive response to openness extends across both hot and cold, poor and rich. The nega- tive exposure to increasing agricultural share becomes marginally significant for cold countries and the negative exposure to tourism is significant for hot and poor countries. Positive ex- posure to oil's share is significant in cold and rich countries. The vulnerability index is never significant and has the wrong sign for hot and poor countries.

Next, we present evidence that foreign exchange market participants interpret the global temperature shock as negative climate news. To do this, we repeat the exercise with the Crimson Hexagon negative sentiment climate change news index (CHNEG) constructed by Engle et al. (2020). This is a common news based climate risk index focused specifically on negative climate news. Engle et al. (2020) searched major news outlets for the number of articles that reflected "negative sentiment". We estimate local-projection coefficients with this negative news variable, CHNEG, in place of the global temperature shock. The CHNEG variable is only available from January 2008, however, so to compare the exchange rate response to CHENG and the global temperature shock, we re-estimate the response to the temperature shock with the sample starting in January 2008.

Fig. 6 shows the scatter plot of CHNEG betas against global temperature betas estimated at the 48-month horizon. As can be seen, the response to a CHNEG shock generally is similar to the response to the global temperature shock.

Table 7 shows the regression results using the 48-month CHNEG betas. Looking at the column labeled 'ALL' we see that the signs on all the coefficients are consistent with those under the 'ALL' column in Table 6. Income and openness lose their significance with CHNEG, however. Agriculture becomes significant and the negative exposure to agriculture is driven by hot countries. The negative exposure to tourism and growth is driven by poor countries. The positive response to oil's share is significant at the 10% level for cold countries and at the 5% level for rich countries.

Table 8 reports the results from regressing 48-month horizon global temperature betas estimated on the more recent sample beginning January 2008 to coincide with the sample for CHNEG. These results can

Table 6
Regression of 48-Month Horizon Local Projection Slopes on Country Characteristics.

	ALL	HOT	COLD	POOR	RICH
GDPPC	-0.125	-0.024	-0.230	0.357	-0.193
	(-3.135)	(-0.358)	**(-3.727)**	(1.419)	**(-3.052)**
OPEN	0.037	0.041	0.051	0.057	0.046
	(4.141)	(1.893*)	**(3.900)**	**(2.325)**	**(3.889)**
AGSHR	-0.073	-0.112	-0.322	-0.020	-0.364
	(-1.070)	(-1.378)	(-1.644*)	(-0.255)	(-0.658)
TOURISM	-0.075	-0.081	0.020	-0.096	0.030
	(-1.557)	(-1.887*)	(0.324)	**(-2.186)**	(0.377)
GROWTH	-1.276	-0.196	-1.366	-1.610	-1.079
	(-1.793)*	(-0.115)	(-1.662*)	(-1.720*)	(-0.865)
VULN	-15.137	14.754	-24.938	11.179	-26.680
	(-1.300)	(0.955)	(-0.978)	(0.717)	(-1.065)
OILSHR	0.110	0.047	0.423	0.064	0.619
	(0.856)	(0.403)	**(3.641)**	(0.525)	**(2.566)**
RSQ	0.277	0.448		0.396	
NOBS	73	73		73	

Notes: Bold indicates significance at the 5% level. '*' indicates significance at the 10% level. t-ratios in parentheses.

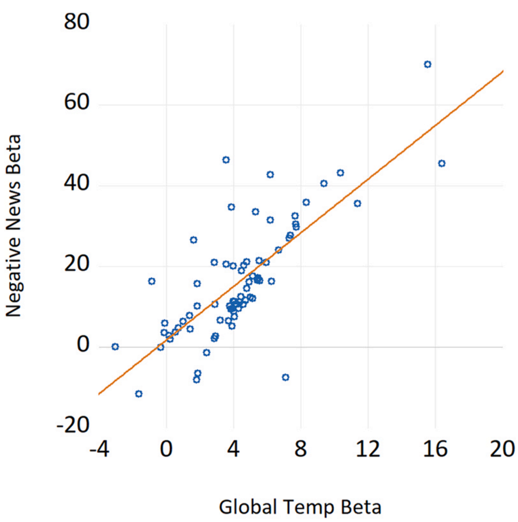

Fig. 6. CHNEG and Global Temperature Betas at 48-Month Horizon. Notes: Betas estimated on sample beginning January 2008.

also serve as an informal assessment of the extent of coefficient instability over time. A source of potential instability is the increased awareness of climate change. Comparing the 'ALL' column in this table to Table 6, the only coefficient to change sign is oil's share. The negative coefficient in the more recent period is driven by hot and poor countries. Poor and hot countries now have a positive response to income. Openness loses its

significance. Negative exposure through agricultural share is driven by hot countries. Negative exposure to tourism through hot and poor countries. The negative exposure to growth remains.

To summarize, negative climate news and temperature are different pieces of information, but the results reported in Tables 7 and 8 show that the exchange rate reaction to them is similar in many respects. The robust (and significant) result is the negative tourism exposure for poor countries, and negative growth exposure (also especially for poor countries). There is a positive response for oil's share for cold and rich countries in the full-sample estimates and negative climate news, which contrasts to the negative response from the subsample responses to temperature for hot and poor countries.

We close this section with an additional comment. The explanatory power of country characteristics on the exchange rate response seems confined as a USD phenomenon, possibly due to the outsized economic and financial importance of the U.S. We also conducted our analysis with the Swiss franc and the British pound as numeraire currencies. The impulse responses for an alternative numeraire amounts to a simple rotation of Eq.(2). While we find significant and heterogeneous impulse responses, they showed little systematic variation with country characteristics.

Table 7
Regression of 48-Month Horizon Local Projection Slopes from CHNEG on Country Characteristics.

	ALL	HOT	COLD	POOR	RICH
GDPPC	-0.162	0.407	-0.131	1.462	0.187
	(-0.714)	(0.996)	(-0.662)	(1.290)	(0.905)
OPEN	-0.032	0.003	-0.021	0.060	-0.056
	(-0.726)	(0.028)	(-0.510)	(0.478)	(-1.573)
AGSHR	-0.475	-0.564	0.221	-0.386	1.324
	(-2.296)	**-2.244**	(0.341)	(-1.260)	(1.660)*
TOURISM	-0.252	-0.279	-0.304	-0.444	0.076
	(-1.624)	(-1.426)	(-1.141)	**(-1.992)**	(0.422)
GROWTH	-4.973	-4.480	-5.481	-9.539	-1.624
	(-1.944)*	(-1.253)	(-1.509)	**(-2.493)**	(-0.664)
NDVULN	-23.954	26.623	-51.234	24.004	-26.674
	(-0.475)	(0.328)	(-0.689)	(0.334)	(-0.421)
OILSHR	0.363	0.020	1.078	-0.150	2.489
	(1.116)	(0.063)	(1.765)*	(-0.611)	**(4.224)**
RSQ	0.242	0.345		0.450	
NOBS	73	73		73	

Notes: Bold indicates significance at the 5% level. '*' indicates significance at the 10% level.

Table 8
Regression of 48-Month Horizon Local Projection Slopes from Global Temperature on Country Characteristics. Sample begins January 2008.

	ALL	HOT	COLD	POOR	RICH
GDPPC	-0.018	0.122	-0.028	0.449	0.029
	(-0.469)	(1.843)*	(-0.692)	**(2.738)**	(0.802)
OPEN	-0.006	0.008	-0.003	0.020	-0.008
	(-0.760)	(0.417)	(-0.341)	(0.801)	(-1.208)
AGSHR	-0.082	-0.099	-0.086	-0.051	0.201
	(-1.849)*	**(-2.220)**	(-0.454)	(-1.247)	(0.978)
TOURISM	-0.089	-0.117	-0.044	-0.139	0.019
	(-2.760)	**(-4.174)**	(-0.773)	**(-4.016)**	(0.489)
GROWTH	-1.123	-0.636	-1.464	-2.060	-0.479
	(-1.804)*	(-0.817)	(-1.553)	**(-3.013)**	(-0.635)
NDVULN	-8.136	6.975	-12.617	10.351	-13.208
	(-1.083)	(0.553)	(-0.727)	(1.072)	(-0.998)
OILSHR	-0.085	-0.167	0.132	-0.199	0.485
	(-1.284)	**(-2.108)**	(0.825)	**(-2.406)**	(1.196)
RSQ	0.240	0.367		0.482	
NOBS	73	73		73	

Notes: Bold indicates significance at the 5% level. '*' indicates significance at the 10% level.

7. Conclusion

This paper presents evidence that temperature shocks move real exchange rates. As a national asset, the exchange rate values current and future relative fundamentals, and its response to temperature shocks can inform how market participants view the economic consequences of those shocks.

Our ultimate interest is in how climate change impacts national economies. However cli- mate change is a gradually evolving process which doesn't lend itself well to time-series re- gression. As a result, we followed the empirical literature by analyzing the real exchange rate response to temperature shocks. The responses to global temperature shocks are systematically related to country characteristics. At the 48 month horizon, a country's currency more likely to depreciate if the country has grown faster, is more dependent on agriculture and tourism.

Future analysis might examine the interrelationship between real exchange rate responses to weather or climate variables and other asset returns such as national stock indices with a focus on cross-country response heterogeneity. The impact of climate change is felt differently across countries, due to differences in location, economic structure and stage of development. Studying how asset prices process climate change shocks can help us to better understand potential future damages.

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