INTERNATIONAL MONETARY FUND

Weather Shocks and Exchange Rate Flexibility

Selim Elekdag and Maxwell Tuuli

WP/22/93

2022
MAY

WORKING PAPER

WP/22/93

IMF Working Paper
Middle East and Central Asia Department

Weather Shocks and Exchange Rate Flexibility

Prepared by Selim Elekdag and Maxwell Tuuli*

Authorized for distribution by Nicolas R. F. Blancher
May 2022

ABSTRACT: This paper assesses the stabilization properties of fixed versus flexible exchange rate regimes and aims to answer this research question: Does greater exchange rate flexibility help an economy's adjustment to weather shocks? To address this question, the impact of weather shocks on real per capita GDP growth is quantified under the two alternative exchange rate regimes. We find that although weather shocks are generally detrimental to per capita income growth, the impact is less severe under flexible exchange rate regimes. Moreover, the medium-term adverse growth impact of a 1 degree Celsius increase in temperature under a pegged regime is about –1.4 percentage points on average, while under a flexible regime, the impact is less than one half that amount (–0.6 percentage point). This finding bolsters the idea that exchange rate flexibility not only helps mitigate the initial impact of the shock but also promotes a faster recovery. In terms of mechanisms, our findings suggest that the depreciation of the nominal exchange rate under a flexible regime supports real export growth. In contrast to standard theoretical predictions, we find that countercyclical fiscal policy may not be effective under pegged regimes amid high debt, highlighting the importance of the policy mix and precautionary (fiscal) buffers.

RECOMMENDED CITATION: Elekdag, S., and Tuuli, M. (2022), Weather Shocks and Exchange Rate Flexibility, IMF Working Paper WP/22/93 , Washington DC: International Monetary Fund.

JEL Classification Numbers:	F31, F4, O40, O44, Q54, Q56
Keywords:	Exchange rate regimes; Economic growth; Climate change
Author's E-Mail Address:	SElekdag@imf.org, MTuuli@imf.org

---

* The authors would like to thank Subir Lall for insightful discussions. We would also like to thank participants at the MCD departmental seminar series for the helpful discussions and suggestions. We are grateful to Sebastian Acevedo Mejia, Claudio Baccianti, Mico Mrkaic, Natalija Novta, Evgenia Pugacheva, and Petia Topalova for sharing their dataset. We also benefitted from discussions by Augustus J. Panton, Bas Bakker, Nicolas Fernandez-Arias, K. Naidoo, H. Nguyen, Chadi Abdallah, and Sanaz Sadoughi. The views expressed herein are those of the author and should not be attributed to the IMF, its Executive Board, or its management.

Executive Summary

This paper empirically assesses contrasting theoretical predictions about the macroeconomic stabilization properties of fixed and flexible exchange rate regimes by quantifying the impact of weather shocks on per capital real GDP growth. The weather shocks are computed as annual variations in temperature and precipitation. Although climate change has been attributed to human activity (IPCC, 2021), weather shocks are unpredictable and not directly caused by economic decisions, especially those relating to exchange rate policy. To quote a saying attributed to Mark Twain: "Climate is what we expect, weather is what we get."

The results of the paper provide broad support for the notion that greater exchange rate flexibility can help emerging market and developing countries (EMDCs) better adjust to shocks. In particular, fixed exchange rate regimes perform considerably worse when weather shocks occur relative to flexible regimes, on average. For example, a 1 degree Celsius increase in temperature would decrease real per capita income growth by 1.4 percentage points upon impact under a peg, whereas the corresponding decrease under a non-pegged exchange rate regime would be 1 percentage point. Importantly, while the medium-term adverse growth impact under the peg is about –1.4 percentage points on average, under the flexible regimes, this impact is less than one half that amount (–0.6)—and not statistically significant. In other words, greater exchange rate flexibility not only helps mitigate the initial impact of the shock, but also promotes a faster recovery.

The underlying adjustment mechanism also seems to be generally consistent with that identified in the standard theoretical literature. The medium-term increase in real export growth is 1.4 percentage points under flexible exchange rate regimes as compared to 5.5 percentage point decline under the pegs. That is, consistent with the adjustment through a depreciation of the nominal exchange rate, there is a significant export response for non-pegged regimes. Although we would expect a countercyclical fiscal policy stance in response to the weather shocks under pegged regimes, it appears that the prevalence of high debt restrains the use and effectiveness of this macroeconomic stabilization tool, highlighting the importance of the policy mix and precautionary (fiscal) buffers.

The role of heterogeneity across countries needs to be acknowledged. In particular, a fixed exchange rate regime may have advantages over flexible ones for some countries, including under certain circumstances. Likewise, the adoption of greater exchange rate flexibility should be done to ensure a smooth transition and with a new, credible nominal anchor.

Introduction

Well before the abandonment of the Bretton Woods systems, economists debated the macroeconomic stabilization properties of exchange rate regimes. In fact, notwithstanding the celebrated theoretical literature on the subject, the choice of FX has been evolving for more than a century (Bordo, 2003). Proponents of flexible exchange regimes argue that nominal exchange rate movements can restore equilibrium faster, particularly in economies with sticky prices and wages. According to the theoretical framework that is typically employed, when monetary policy is loosened the depreciation of the domestic currency can help offset the effects of an adverse shock by fostering an export-driven recovery. The attendant increase in prices can also reduce real wages—thereby hastening the adjustment process. In contrast, the same shock under a fixed exchange rate regime would lead to a decline in output until prices and wages fall sufficiently, with the pace of adjustment determined by nominal rigidities.[1]

Despite the potential benefits of greater exchange rate flexibility, many countries still maintain fixed exchange rate regimes. Although there are many emerging market and developing countries (EMDCs) that claim their exchange rates are flexible, their de facto exchange rate regimes are quite rigid. In fact, according to the classification based on Ilzetzki, Reinhart, and Rogoff (2019), the share of de facto hard pegs has increased in recent decades, despite a downward trend since the 1940s (which accelerated in the early 1970s). For instance, although the share of hard pegs declined to 37 percent of the total number of countries in the early 1990s, this share has increased to approximately 50 percent in recent years (**Figure 1**).[2]

There are well-documented theoretical reasons why a country may opt for a pegged exchange rate regime. A fixed exchange rate is relatively transparent and a simple anchor for monetary policy, and by implementing such a regime, countries with weaker institutions can "import" monetary credibility by anchoring to a currency with a credible central bank. Likewise, monetary policy can be procyclical in some EMDCs, limiting an important component of the adjustment process in flexible rate regimes (Kaminsky and others, 2004; Chinn and Wei, 2013). Fixed rate regimes can also reduce exchange rate variability and lower transaction costs, thereby stimulating trade, investment, and growth (Frankel and Rose, 2002). Moreover, in countries with less-developed financial sectors, economic agents may not have the financial tools to hedge currency risks. In contrast to some of the literature on this topic, Elekdag and Tchakarov (2007) show that fixed exchange rate regimes can be welfare enhancing in economies with significant liability dollarization. At the same time, exchange rate pegs can create incentives for (excessive) dollarization, thereby leading to balance sheet vulnerabilities, and inhibit the development of hedging instruments.

Earlier empirical studies contrasting these theoretical predictions have been complicated by econometric issues. The exchange rate regime is not a random occurrence but rather a policy choice—a fact that has confounded statistical inference in earlier studies. The choice of regime can influence a country's openness and trade patterns and, consequently, the nature of shocks that a country experiences, including their frequency and intensity. This line of reasoning is clearly illustrated in textbook Mundell-Fleming models.

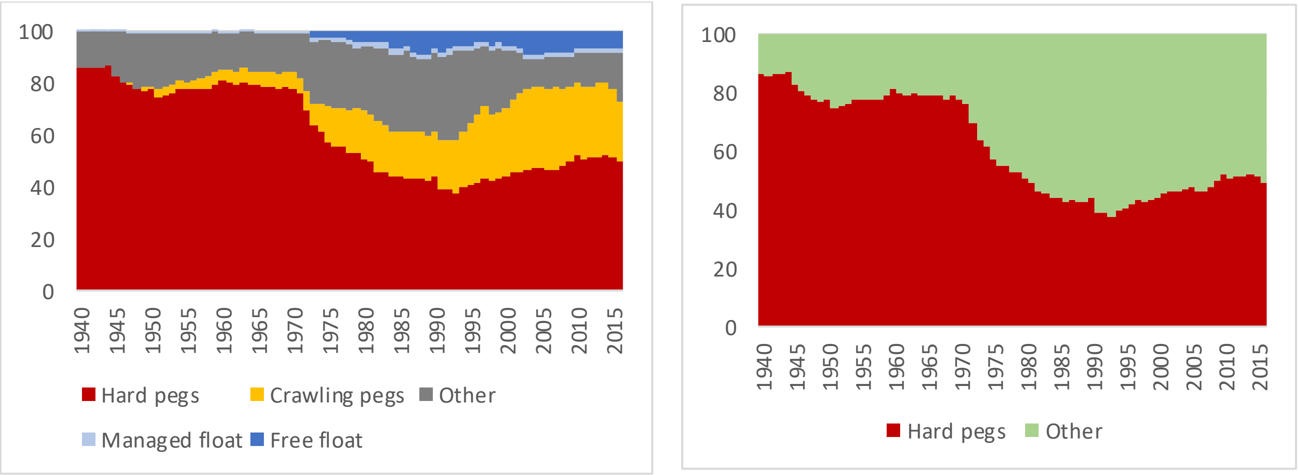
---

[1] See the seminal studies by Friedman (1953), Mundell (1961), Fleming (1962), and Dornbusch (1976). For a more recent literature review, empirical investigations, and theoretical presentations, see, for example, Frankel (2012), Chinn and Wei (2013), Schmitt-Grohe and Uribe (2017). For a more recent theoretical framework that analyzes monetary policy regimes in emerging and developing economies where climate-related natural disasters are major macroeconomic shocks, see Cantelmo and others (2022).

[2] These trends are confirmed using IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER) database.

Policymakers may also choose a particular regime because of the type, occurrence, and severity of shocks that they expect to receive. A case in point is the prevalence of fixed exchange rate regimes implemented by many commodity exporters. Taken together, these possibilities can clearly affect econometric inference.

Figure 1: Evolution of de Facto Exchange Rate Arrangements
(In percent of total countries)



Source: Ilzetzki, Reinhart, and Rogoff (2019).
Notes: Hard pegs in both panels comprise exchange regimes without a legal tender, preannounced pegs or currency board arrangements, preannounced horizontal bands with arrow bands, and de facto crawling pegs. Crawling pegs comprise preannounced crawling pegs, preannounced narrow crawling bands, de facto crawling pegs, and de facto narrow crawling bands. "Other" in the left panel represents regimes that are neither hard pegs, crawling pegs, managed or freely floating; whereas "Other" in the right panel represents regimes that are not hard pegs.

This paper builds upon earlier studies by using weather shocks to empirically assess the contrasting theoretical predictions about exchange rate regimes and the adjustment to shocks. The key research question is this: Does greater exchange rate flexibility help an economy's adjustment to weather shocks? The weather shocks are based on Acevedo and others (2020) and are computed as annual variations in temperature and precipitation. Although climate change (in particular, rising temperatures) have be attributed to human activity (IPCC, 2021, Acevedo and others, 2017), weather shocks can be considered unpredictable and not directly caused by economic decisions, especially those relating to exchange rate policy. To quote a saying attributed to Mark Twain: "Climate is what we expect, weather is what we get."[3]

The exogenous nature of weather shocks makes them good candidates to help identify the role of the exchange rate regime in the adjustment process. That said, while unpredictable, weather shocks do cluster within certain geographic areas and can affect certain countries disproportionately. For example, EMDCs tend to be hotter than advanced economies, rendering them more sensitive to temperature shocks (Acevedo and

---

[3] More technically, climate refers to a distribution of weather outcomes for a given location, while weather refers to a realization from that distribution. Climate change typically implies that the whole distribution of outcomes shifts, with a possible increase in the likelihood of extreme outcomes. Likewise, the shape of the distribution can change with the fattening of the tails implying a greater probability of potentially catastrophic damage. As argued by Weitzman (2011), the fattening of the tails—the increase in the probability of potentially irreversible and catastrophic damages—justifies decisive policy actions to stabilize greenhouse gas concentrations in the atmosphere ("climate change mitigation") and adjust to the changing climate ("adaptation").

others, 2017). Therefore, the empirical framework includes time-fixed effects to account for time-invariant, country-specific differences (including average growth, size, latitude, and other geographic characteristics), and regional differences that can vary over time—which control for the common effect of all annual shocks across countries within a region (for example, the Caribbean is notoriously prone to seasonal hurricanes). In sum, we quantify the impact of weather shocks on real per capita income growth under pegged versus non-pegged exchange rate regimes.

The results of the paper provide broad support for the notion that greater exchange rate flexibility can help EMDCs better adjust to shocks. The underlying adjustment mechanisms also seem to be generally consistent with those identified in the standard theoretical literature. Therefore, while a credible fixed exchange rate regime can be appropriate for an EMDC, the results in this paper suggest that there are likely to be sizeable costs associated with such a policy. In particular, if weather shocks resemble other types of shocks, then the costs of pegs could be quite high in EMDCs that frequently experience large adverse shocks.

In terms of the quantitative results, fixed exchange rate regimes perform considerably worse when weather shocks occur relative to flexible regimes on average. For example, a 1 degree Celsius increase in temperature would decrease real per capita income growth by 1.4 percentage points upon impact under a peg, whereas the corresponding decrease under a non-pegged exchange rate regime would be 1.0 percentage point.

Moreover, while the medium-term adverse growth impact under the peg is about –1.4 percentage points on average, under the flexible regimes, the impact is less than one half that amount (–0.6), which is not statistically significant. In other words, greater exchange rate flexibility not only helps mitigate the initial impact of the shock, but also promotes a faster recovery.

The results on the adjustment channels are also quite stark. The medium-term increase in real export growth is 1.4 percentage points under flexible exchange rate regimes as compared to a 5.5 percentage point decline under the pegs. That means that there is a significant export response for non-pegged regimes, consistent with the adjustment through a depreciation of the nominal exchange rate.

Although we would expect a countercyclical fiscal policy stance in response to the weather shocks under pegged regimes, it appears that the prevalence of high debt restrains the use and effectiveness of this macroeconomic stabilization tool, highlighting the importance of the policy mix and precautionary (fiscal) buffers.

The role of heterogeneity across countries needs to be acknowledged. In particular, a fixed exchange rate regime may have advantages over a flexible regime for some countries under certain circumstances. Likewise, the adoption of greater exchange rate flexibility should be done to ensure a smooth transition and with a new, credible nominal anchor.

In general, this paper represents a synergy between the classic literature contrasting the macroeconomic stabilization properties of exchange rate regimes discussed earlier and a rapidly growing body of research that applies panel econometric methods to examine how weather shocks influence economic outcomes (see, Dell, Jones, and Olken, 2014). In particular, this paper is closest to Ramcharan (2007) and Acevedo and others (2020), and we build upon both along several notable dimensions.

Ramcharan (2007) uses earthquakes and windstorms to evaluate the stabilization properties of fixed versus flexible exchange rate regimes. Although commonly used in earlier studies (see, for example, Bluedorn, 2005; Yang, 2005), a key shortcoming with this approach is that the natural disaster variables are predominantly binary in nature. For example, under this method an earthquake that registered a value of 2 on the Richter scale (an inconsequential occurrence that can only be detectable with sensitive seismic equipment) is considered on par with a disastrous Richter scale 8 event—in other words, such shocks cannot be differentiated based on their intensity, in contrast to the weather shocks used in this paper. We also build upon Ramcharan (2007) by refining the analysis. For instance, we consider an extended set of variables when investigating the channels through which the choice of regime affects economic growth (for instance, the role of debt). Moreover, we included country and region-time fixed effects terms in our baseline specifications, which, inter alia, control for important factors such as geographic location, size, and other dimensions that are likely to influence the relationship between weather shocks and real per capita GDP growth. Following Jorda (2005), we use local projections methods that conveniently trace out the impact of the shocks on growth along with their medium-term implications. We also consider a longer sample that adds 15 more years to the analysis.

In a series of studies, Acevedo and others (2017, 2019, 2020) extend the pioneering work of Dell, Jones, and Olken (2012) and Burke, Hsiang, and Miguel (2015).[4] In particular, Acevedo and others (2020) exploit the annual variation in temperature and precipitation to estimate their causal effect on aggregate economic activity and the underlying factors of production. In a companion paper, they explore the extent to which macroeconomic policies, structural policies, and institutions can mitigate the negative relationship between temperature shocks and output in countries with warm climates. We build upon the work of Acevedo and others (2019) by focusing on the role of exchange rate regimes and extend their analysis by attempting to understand why the impact and recovery are significantly worse under fixed exchange rate regimes. Through our deeper investigation of the underlying mechanisms at work, and consistent with theoretical predictions, we find evidence for a differentiated export response. Furthermore, a set of novel exercises uncovers that limited fiscal space could be restraining the countercyclical policy response that would be expected to be greater under exchange rate pegs.

The layout of the rest of the paper is standard. The next section discusses the empirical framework, data, and stylized facts, which is followed by our main results and then a dedicated section on robustness analysis. The penultimate part of the paper discusses the empirics of key underlying mechanisms, which is followed by the conclusion.

---

[4] A long-debated argument in the economic literature is how temperature and precipitation can affect economic growth. Earlier studies have associated hot climates with lower economic growth in cross-sectional analysis (see Sachs and Warner 1997; Gallup, Sachs, and Mellinger 1999; Nordhaus 2006). However, this raises questions about whether average temperatures, often used in the analyses, proxies for institutional variables that are more relevant for long-run growth. The more recent literature using within country deviations in temperature and precipitation finds evidence of a negative relationship between temperature and precipitation changes on one hand and economic growth on the other (see Dell, Jones, and Olken (2012); Kahn and others (2019). Thus, it seems evident in recent literature that fluctuations in temperature and precipitation result in a negative impact on per capita income growth. See also Graff Zivin and Niedell (2010), Alesina and others (1996), Riot Commission (1968), Carlsmith and Anderson (1979) and Boyanowsky (1999) on important channels through which weather shocks can affect growth.

Empirical Framework, Data, and Stylized Facts

Empirical Framework

Our empirical framework builds on the existing literature and identifies how annual fluctuations in temperature and precipitation affect macroeconomic performance under different exchange rate regimes. We use Jordà's (2005) local projection method to trace the impulse response function of real per capita GDP to weather shocks. As noted by Stock and Watson (2007), this approach does not impose the dynamic restrictions embedded in vector autoregressions or autoregressive distributed lag specifications and is particularly suited to estimating nonlinearities in the dynamic response. We derive the impulse response by estimating a set of regressions:

$$y_{c,t+h} - y_{c,t-1} = \beta_1^h Regime_{c,t} + \beta_2^h Shock_{c,t} + \beta_3^h Shock_{c,t} * Regime_{c,t} + Other \tag{1}$$

in which *c*, *t*, and *h*, denote country, time (in years), and the estimation horizon (from 0, which captures the impact effect, up to horizon 5, which captures the effect 5 years after the shock). Regressions for each horizon are estimated for each horizon *h* separately. The dependent variable is the cumulative growth of real per capita GDP between horizons t − 1 and t + h, measured as the difference in the natural logarithms. The regressions control for one lag of the dependent and the independent variables and for forwards of the shock variables, as suggested by Teulings and Zubanov (2014); country fixed effects control for all time-invariant country differences, such as latitude, size, and average growth rates, while time fixed effects interacted with region dummies control for the common effect of all annual shocks across countries within a region, that is: $Other = \beta_4^h Regime_{c,t-1} + \beta_5^h Shock_{c,t-1} + \sum_{j=1}^{h-1} \gamma_1^h \; Shock_{c,t+h-j} + \rho^h \Delta y_{c,t} + \varphi_c^h + \varphi_{r,t}^h + e_{c,t}$. To mitigate overcontrolling bias, the specification is intentionally parsimonious for two reasons. First, many of the determinants of growth, typically included in standard growth regressions (for example, institutional quality) may themselves be shaped by weather shocks and are thus not part of the baseline estimation. Second, to the extent that these are time-invariant and country-specific, they are captured by the fixed effects.[5]

Within this framework, the effect of a weather shock, such as a 1-degree Celsius increase in temperature, on the level of output at horizon *h* can be obtained by differentiating equation (1) with respect to temperature—consider the case with $h=0$:

$$\frac{\Delta(y_{c,t} - y_{c,t-1})}{\Delta Shock_{c,t}} = \beta_2^0 + \beta_3^0 * Regime_{c,t}$$

The main coefficient of interest is β_3^0. Under a peg, $Regime_{c,t} = 1$, textbook Mundell-Fleming would seem to suggest the following hypothesis H_0: $\beta_3^h \leq 0$ given the absence of nominal exchange rate fluctuations to help facilitate macroeconomic adjustment. Throughout the paper, we will compare the impact of the weather shocks

---

[5] The estimation framework is premised on two important assumptions: First, we plausibly argue that weather shocks are exogenous shocks (and not influenced by the choice of exchange rate regime). Second, the framework assumes that weather shocks do not systematically alter the exchange rate regime. When discussing the robustness of our main results in the next section, we argue that this assumption is reasonable.

on real per capita GDP growth under fixed exchange rate regimes (“pegs”) with coefficients $(\beta_2^h + \beta_3^h)$ with flexible exchange rate regimes (“non-pegs”) with coefficient β_2^h over horizons h.[6]

Data

The main data sources include the IMF World Economic Outlook (WEO), the World Bank World Development Indicators (WDI), and the University of East Anglia’s Climate Research Unit (CRU) historical temperature and precipitation databases.[7] Table A1 in the appendix provides the details on the data sources and definitions of the variables used in the analysis. Per capita GDP is taken from the WEO and WDI, while historical temperature and precipitation are from the CRU. We use the database in Acevedo and others (2020) who construct average annual temperature and precipitation time series by aggregating weather data at the grid-cell level, provided by CRU at 0.5 × 0.5 degree resolution, to the level of the country using the 1950 population in each cell as weights. This method accounts for differences in population density within countries and captures the average weather experienced by a person in the country.

Stylized Facts

As noted elsewhere, global temperatures have increased by roughly 1 degree Celsius over the past century (IPCC, 2021). The increase in temperature has occurred in all regions of the world, with an accelerating trend starting in the 1970s (**Figure 2**). The median temperature over the first 15 years of this century, compared with the first 15 years of the past century, was 1.5 degrees Celsius higher in advanced economies (AEs) and about 0.7 degree Celsius higher in emerging market and developing countries (EMDCs). However, although most of the warming occurred in AEs, the median temperature in EMDCs was more than twice the median AE.

These temperature differences are important because as noted in Acevedo and others (2020), in countries with high average temperatures, an increase in temperature dampens economic activity, where it has the opposite effect in much colder climates. Indeed, since most AEs are in colder locations, a marginal temperature increase does not materially affect growth. However, many EMDCs have much hotter climates and a rise in temperature significantly lowers per capita income growth. Therefore, as in Acevedo and others (2020), in our baseline analysis, we initially restrict the sample to EMDCs with an average annual temperature exceeding 15 degrees Celsius. Later, we consider a full sample of countries to assess the robustness of our main findings.

Table 1 presents a standard descriptive statistics of the data used in the empirical analysis. In addition, the table splits the sample in 1990 as a first pass at assessing developments over time. The main takeaway is that average temperatures have increased by roughly 1 degree Celsius over the two sub-samples (a result which is statistically significant at the 1 percent level), confirming the patterns discussed above. At the same time, average real per capita income growth has declined slightly over the two periods.

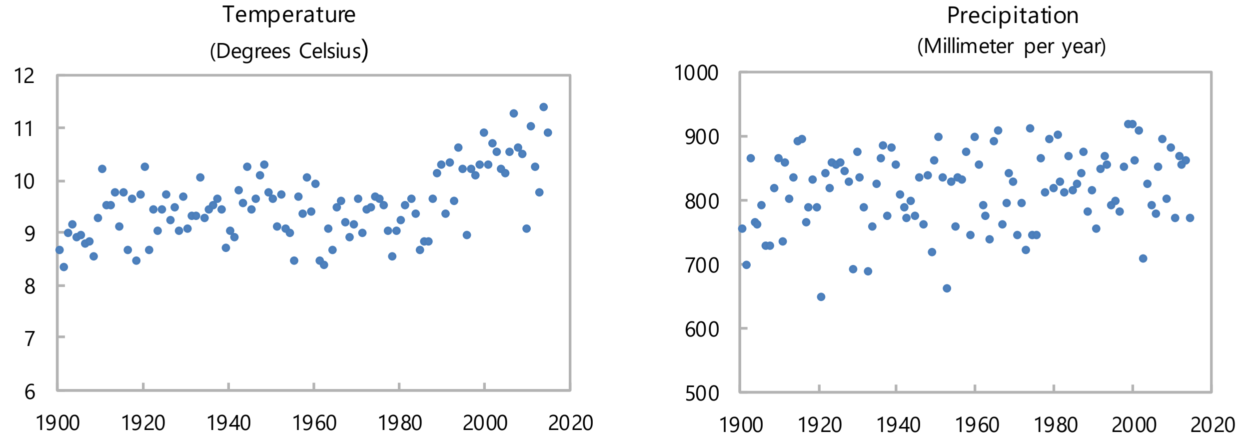
---

[6] Although previous studies find that β_2 is negative (Acevedo and others, 2020; Dell, Jones, and Olken, 2012; Burke, Hsiang, and Miguel, 2015) as noted by Cavallo and others (2013) a priori, economic theory is inconclusive on the impact of natural disasters on economic growth.

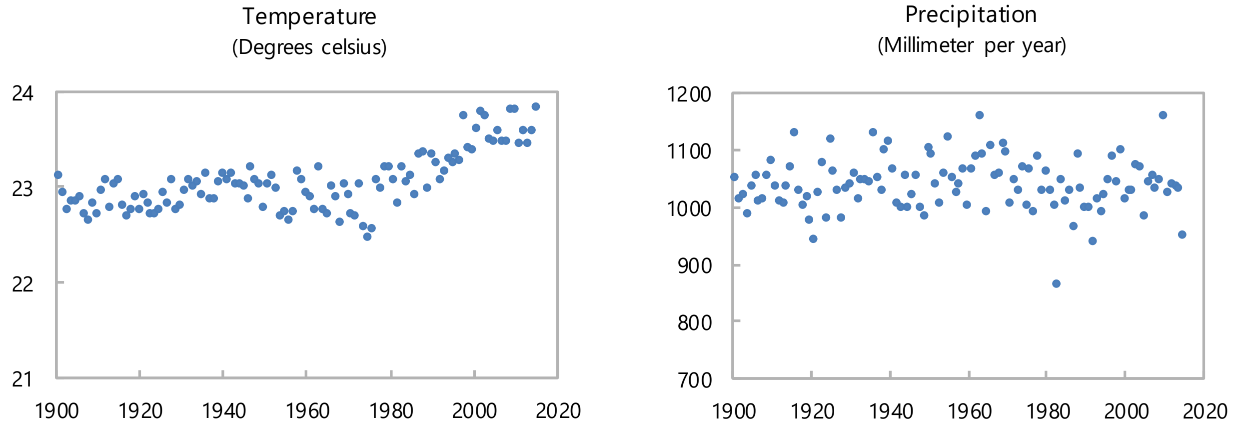
[7] We are grateful to Sebastian Acevedo Mejia, Claudio Baccianti, Mico Mrkaic, Natalija Novta, Evgenia Pugacheva, and Petia Topalova for sharing their database.

Figure 2: Evolution of Temperature and Precipitation across different Country Groups.

Advanced Economies



Emerging Market and Developing Economies



Source: Acevedo and others (2020) and authors' calculations.

Note: Grid-level median annual temperature and precipitation data are aggregated to the country-year level using 1950 population weights.

Table 1: Summary Statistics

				Percentiles						
VARIABLES	N	Mean	SD	p1	p5	p25	p50	p75	p95	p99
Temperature (degree Celsius)	13,170	18.9	7.7	1.2	5.6	11.9	21.4	25.5	27.7	28.8
Precipitation (100 millimeter per year)	13,962	11.6	8.4	0.0	0.0	5.4	9.8	16.4	28.1	34.8
Per capita income growth	9,842	1.8	6.5	-17.2	-7.2	-0.3	2.2	4.5	9.3	17.0
Inflation	7,368	25.8	351.4	-3.0	-0.3	2.3	5.2	10.8	38.6	235.6
Exports (percent of GDP)	7,882	36.0	28.3	4.2	8.1	18.1	28.9	45.8	82.5	158.4
Real exports growth	5,722	-3.7	31.6	-120.1	-41.6	-10.1	0.9	9.8	24.2	44.5
Real Effective Exchange Rate growth	5,919	-0.4	13.0	-39.8	-14.3	-3.4	0.3	3.7	12.0	26.0
Real Wage Growth	1,938	3.1	7.5	-14.0	-5.5	-0.3	1.7	5.0	16.4	27.5
Real Government Consumption growth	7,077	4.0	13.6	-37.3	-14.9	-0.3	3.9	8.5	22.0	45.1
Government Debt (percent of GDP)	7,560	55.3	58.7	2.7	7.8	23.7	42.3	68.8	141.2	260.5
Pre 1990 (1950-1989)										
Temperature (degree Celsius)	7,980	18.6	7.7	-0.6	5.3	11.7	21.1	25.3	27.3	28.4
Precipitation (100 millimeter per year)	8,460	11.6	8.4	0.0	0.0	5.4	9.8	16.5	28.1	34.6
Per capita income growth	4,521	1.9	6.1	-17.2	-7.7	-0.5	2.3	4.8	9.9	16.8
Post 1990 (1990-2015)										
Temperature (degree Celsius)	5,190	19.4	7.7	1.3	6.2	12.3	21.9	25.9	28.1	29.2
Precipitation (100 millimeter per year)	5,502	11.5	8.5	0.0	0.0	5.3	9.8	16.3	28.1	34.9
Per capita income growth	5,321	1.8	6.8	-16.7	-6.9	-0.2	2.1	4.3	8.8	17.1

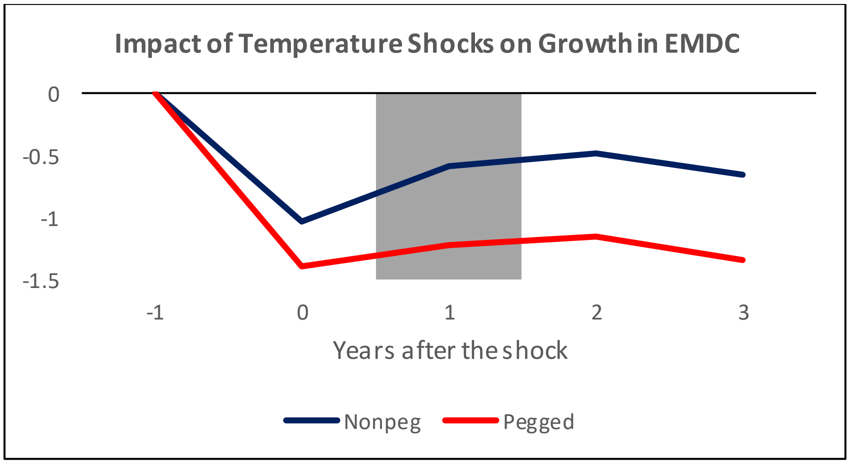
Source: Authors' calculations.

Notes: Details of the countries used in the analysis are provided in Appendix Table A2.

Main Results

The results from estimating equation (1) are illustrated in **Figure 3** with further details presented in **Table 2**. **Figure 3** summarizes the main result in the paper: The implications on growth associated with the adverse weather shocks are worse under fixed exchange rate regimes. This finding is especially robust in the case of temperature shocks. Indeed, the dynamic responses under the peg are statistically significant upon impact and over the course of the following three years after the shock. At the same time, the differences in the dynamic responses are statistically significant in the year following the shock (which is indicated by the shading in the figure). Although the differences between the regimes appear starker in the case of the precipitation shocks (results are not presented here), the statistical significance of these results tends to be less consistent, a result similar to Acevedo and others (2019). Therefore, for the remainder of the paper, we will primarily concentrate our attention on the temperature shocks (the full results, including with the precipitation shocks, are presented in the Appendix).

Figure 3: Impact of 1^{0}C Temperature Shock on Growth
(percent)



Source: Authors' calculations.

Notes: The figure shows the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^{0}C.

The quantitative estimates of the effect of the temperature shocks are presented in **Table 2.** A 1-degree Celsius increase in temperature would decrease real per capita income growth by 1.4 percentage points upon impact under a peg exchange rate regime, whereas the corresponding decrease under a non-pegged exchange rate regime would be 1.0 percentage point, on average across the sample of EMDCs. Moreover, while the medium-term (the average over the five-year horizon) adverse growth impact under the peg is about –1.4 percentage points, under the flexible regimes, the impact is less than one half that amount (–0.6). Furthermore, while the negative growth impact under the peg is statistically significant up to four years after the shock, under non-pegs, only the impact coefficient is statistically significant. In other words, greater exchange rate flexibility not only helps mitigate the initial impact of the shock, but also promotes a faster recovery.

Table 2: Temperature Shocks, Growth, and Exchange Rate Regimes
(percent)

	Per Capita Income Growth: EMDC				
Horizon	Nonpeg		Pegged		p_value
0	–1.034	***	–1.395	***	0.109
	(0.347)		(0.344)		
1	–0.589		–1.219	**	0.050
	(0.462)		(0.470)		
2	–0.477		–1.156	**	0.109
	(0.500)		(0.568)		
3	–0.662		–1.343	**	0.203
	(0.612)		(0.674)		
4	–0.852		–1.912	**	0.075
	(0.840)		(0.905)		
5	–0.285		–1.572		0.048
	(0.877)		(0.963)		
Adjusted R2			0.34		
Number of countries			110		
Number of observations			3268		

Source: Authors' calculations.
*Notes: The table shows the impact of 1^0C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^0C.*

How do our results compare with earlier studies?

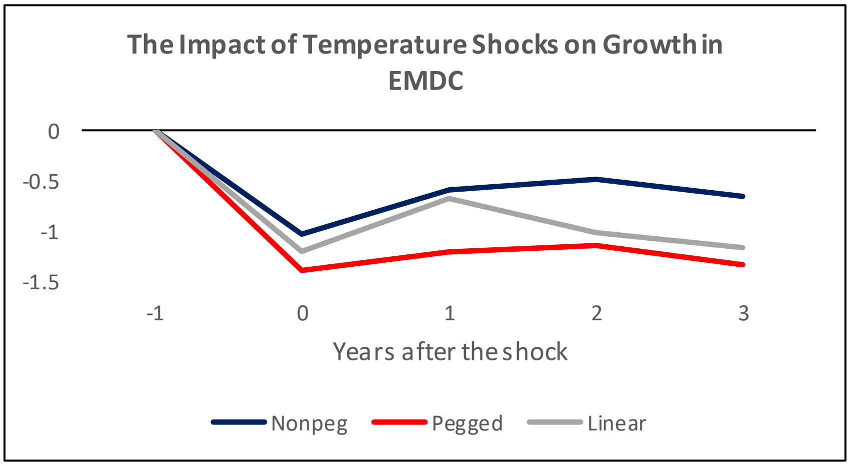
Figure 4 compares the baseline results with a linear specification that includes the weather shocks but omits the regime indicator variable and its interaction with the shocks. Intuitively, the results from the linear regression lie in between growth outcomes of the two regimes. In this way, we broadly replicate the earlier literature that investigated the impact of climate shocks on growth (for example, Dell, Jones, and Olken, 2012).[1]

---

[1] To further replicate and extend the findings in the literature (and to verify a key channel of impact), we also re-estimated equation (1) for countries where the agricultural sector as a share of GDP is above the sample median and found that the impact under the peg can be even more severe for such countries (especially in the medium term where the impact coefficients are larger in absolute value and statistically significant at the 5 percent level). These results have been excluded for brevity and are available upon request.

This figure is another illustration of the potential advantages of flexible exchange rate regimes in contrast to pegs when it comes to shoring up macroeconomic resilience and fostering a stronger economic rebound.

Figure 4: Comparison with earlier studies: Impact of 1^0C Temperature Shock on Growth (percent)



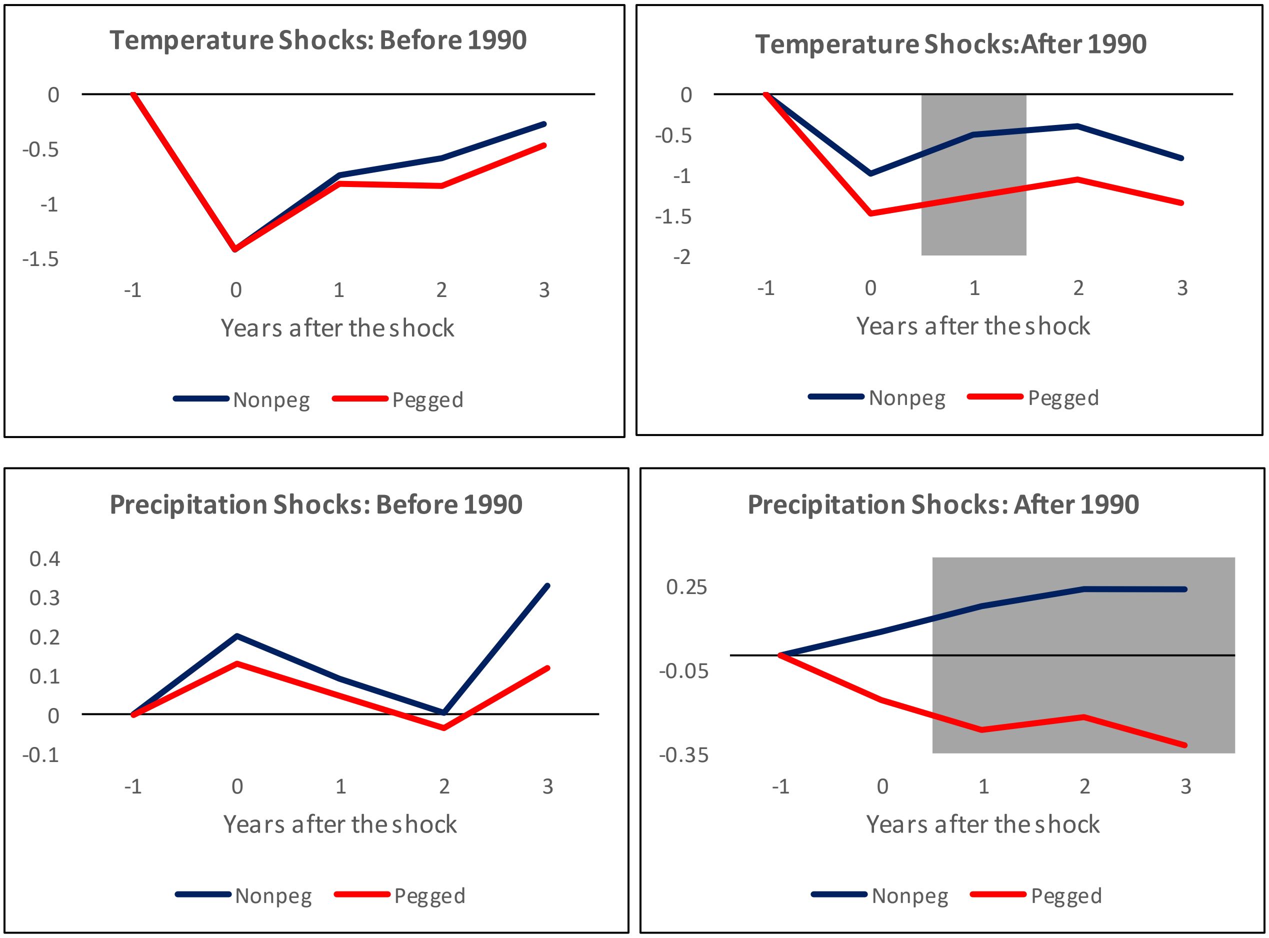
Source: Authors' calculations.
Notes: The figure shows the impact of 1^0C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). The linear results are obtained using the same specification but without including the exchange rate regime variable. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^0C.

How do the results change over time?

Given the rising trend in global temperatures, we considered sub-sample analysis where we compare the pre- and post-1990s periods. Alternative break points yield similar results and are therefore not reported. Because temperatures have increased, we could expect a greater adverse growth impact in the latter period. A competing hypothesis is that the potentially unfavorable growth impact may only be relevant for fixed exchange rate regimes. That is, the merits of greater exchange rate flexibility maybe even more compelling in the latter part of the sample.

As illustrated in **Figure 5**, we find that both types of weather shocks have similar growth implications in the pre-1990 sample, but with only the temperature shocks having a short-term statistically significant impact on economic activity (see also **Table A3 and Table A4** in the appendix). In contrast, the post-1990 sample results closely resemble those under the full sample. Regarding temperature shocks, the coefficients over the short- and medium-term, and their statistical significance are similar to the results under the baseline. Turning to the precipitation shocks, in contrast to the full sample estimations, the impact on growth in the post-1990 are statistically significant in the short-run (upon impact) and over the medium term (e.g., *h=4*). Moreover, in the post-1990 the difference in the growth outcomes between the fixed and flexible exchange rate regimes is now statistically significant in the context of the precipitation shocks. Taken together, it appears that the benefits associated with greater exchange rate flexibility have increased over time.

Figure 5: Impact of Weather Shocks over time
(percent)


Temperature Shocks: Before 1990

Temperature Shocks:After 1990

Precipitation Shocks: Before 1990

Precipitation Shocks: After 1990

Source: Authors' calculations.

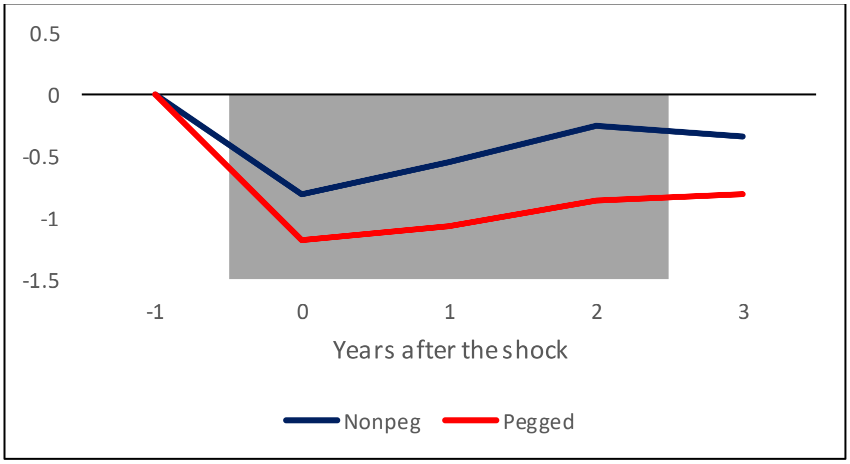
Notes: The figure shows the impact of weather shocks on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. The top panel shows the impact of 1^{0}*C temperature shock on per capita income growth across different exchange rate regimes for periods before and after 1990. The down panel shows the impact of a 100-millimeter increase in precipitation on per capita income growth across different exchange rate regimes for periods before and after 1990. The sample comprises all countries with annual average temperature greater than 15*^{0}*C.*

Robustness Analysis

We conduct several exercises to assess the robustness of the main results. The first exercise considers a broader sample of countries, including AEs as well as EMDCs with average temperatures below 15 degrees Celsius (these include some EMDCs that have cooler climates, such as Albania, Azerbaijan, Bulgaria, Colombia, Peru). Although the dynamic responses are similar to those under the baseline specification, the impact is about half as worse in the case of temperature shocks (**Figure 6**). For instance, we noted above that under a peg a 1-degree Celsius increase in temperature would decrease real per capita income growth by 1.4

percentage points in the baseline specification focusing on EMDCs (with average temperatures above 15 degrees Celsius). With the full sample, this latter impact coefficient is 0.7. This result is intuitive because the sample includes AE and EMDCs that are located in cooler climates (see **Table A5** in the appendix). Recall that earlier research has demonstrated that hot countries, which are overwhelmingly EMDCs, suffer the most from an increase in temperature (Acevedo and others, 2020; Dell, Jones, and Olken, 2012; Burke, Hsiang, and Miguel, 2015).

Figure 6: Robustness: All countries: Temperature Shocks and Growth (percent)



Source: Authors' calculations.

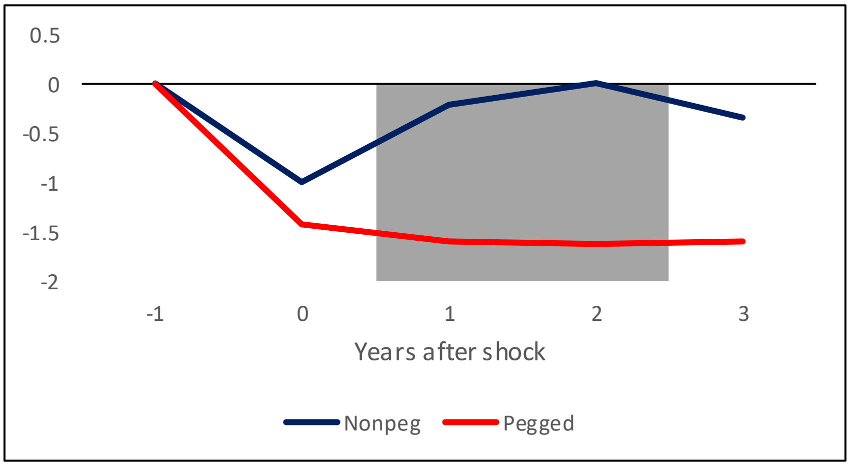
Notes: The figure shows the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. The sample comprises all Emerging Market and Developing Economies.

A key assumption underlying the empirical framework is that weather shocks do not systematically cause changes to the exchange rate regime. However, as noted earlier, the exchange rate regime is a policy decision. Consider the case of a fixed exchange rate regime: After a severe shock, a country may be unable to maintain the peg, and may opt for greater exchange rate flexibility. If such policy decisions occur systematically, this would imply a significant correlation between flexibility exchange rate regimes and severe weather shocks, thereby skewing inference.

To address this concern, we consider temperature shocks in which the exchange rate regime in the year of the shock and in the subsequent year remained identical to the regime that prevailed in the year before the shock. That is, the sample is limited to shocks where the exchange rate regime remains constant over a three-year window beginning in the year before the shock. As shown in **Figure 7** the results are similar to those under the baseline specification (and also robust to a longer constant regime window, see **Table A6** in the appendix).

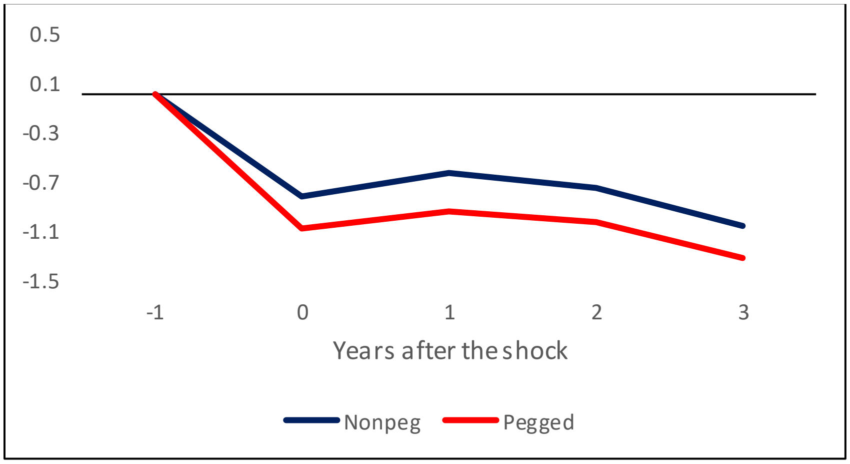
Another sensitivity test considers an alternative classification of exchange rate regimes based on Shambaugh (2004). Using the 2019 update of his dataset yields results that are broadly similar to the baseline specification (**Figure 8**). In particular, the performance is worse under the peg with negative coefficients which are statistically significant upon impact and over the medium term (albeit somewhat smaller in absolute value relative to the baseline specification (see **Table A7** in the appendix).

Figure 7: Robustness: Constant Regimes: Temperature Shocks and Growth
(percent)



Source: Authors' calculations.
Notes The figure shows the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. "Constant Regime" refers to the cases in which the exchange rate regime remains constant over a three-year window beginning in the year before the shock. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^{0}C.

Figure 8: Robustness Analysis: Shambaugh Exchange Rate Regime Classification
(percent)

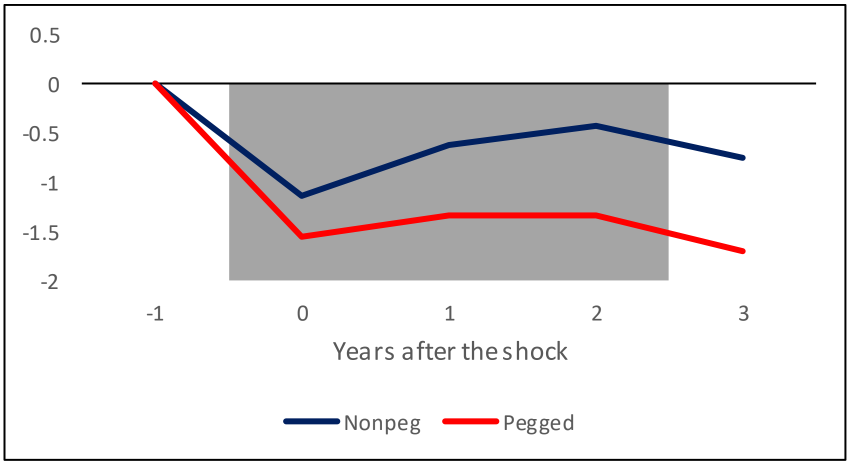


Source: Authors' calculations.
Notes: The figure shows the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients

between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. The exchange rate regime classification used in this figure is obtained from Shambaugh (2004) updated dataset. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^{0}C.

Another set of exercises considers differing the lag length of the baseline specification. For brevity, we only report one alternative specification which considers 3 lags instead of 1 used in the baseline (**Figure 9**). The results are robust to this change (as would be the case if 2 lags were used as well). Quantitatively, the impact coefficients under the peg are larger (implying a greater sensitivity of growth to temperature shocks). More generally, all coefficients are more precisely estimated—all coefficients are statistically significant at the one percent level (see **Table A8** in the appendix). Likewise, the difference across regimes is also statistically significant. Notwithstanding these encouraging results, guided by Box and Jenkins (1976) we adhere to the principle of parsimony, and prefer our more streamlined baseline specification.

Figure 9: Robustness Analysis: Alternative Lag Dynamics: Temperature Shocks and Growth (percent)



Source: Authors' calculations.

Notes: The figure shows the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. We use 3 lags (instead of one as in our baseline specification) in the regression specification used to obtain the analysis in this figure. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^{0}C.

A final robustness exercise considers both shocks in the same regression specification. On one hand, since the shocks can affect economic activity through distinct channels, considering each individually, as done under the baseline, seems natural.[2] On the other hand, countries are confronted with both shocks in any given year, and so, there is a case to include both shocks together. The results are remarkably similar when both shocks are considered in the same specification. The coefficients are quantitatively alike, as is their statistical significance, as can be seen in **Table 3**.

---

[2] Temperature shocks have been studied more extensively in the literature, including on how they affect GDP via their impact on productivity, capital accumulation, and labor supply. Precipitation shocks have been found to disproportionately affect sub-Saharan countries relative to other regions (see Dell, Jones, Olken, 2014).

Table 3: Robustness Analysis: Both Weather Shocks, Regimes, and Growth
(percent)

	Horizon										
	0		1		2		3		4		5
Temp: Nonpeg	-1.095	***	-0.693		-0.587		-0.828		-1.025		-0.400
	(0.339)		(0.441)		(0.490)		(0.601)		(0.843)		(0.880)
Temp: Peg	-1.406	***	-1.204	***	-1.144	**	-1.313	**	-1.856	**	-1.500
	(0.329)		(0.434)		(0.535)		(0.629)		(0.876)		(0.916)
Precip: Nonpeg	0.040		0.096		0.126		0.245		0.312		0.361
	(0.072)		(0.126)		(0.156)		(0.201)		(0.228)		(0.272)
Precip: Peg	-0.052		-0.124		-0.100		-0.125		-0.127		-0.010
	(0.061)		(0.109)		(0.119)		(0.129)		(0.124)		(0.169)
Adjusted R2		0.344									
Number of countries		110									
Number of observations		3268									

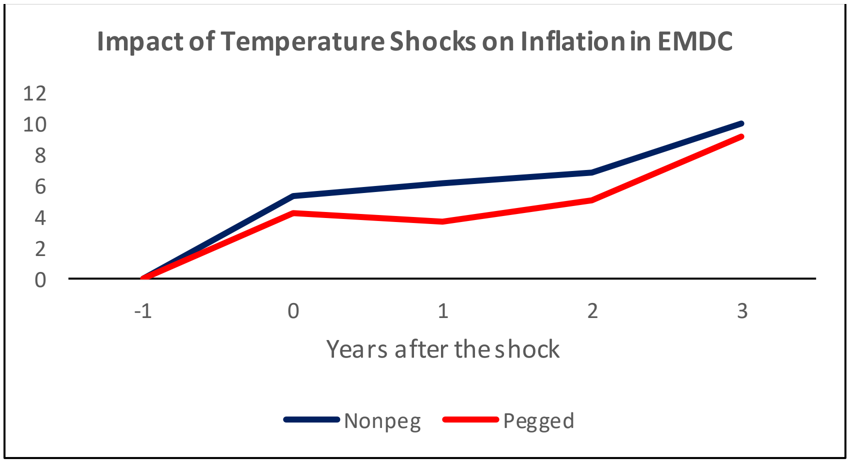
Source: Authors' calculations.
*Notes: The table shows the impact of weather shocks on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. The first two rows show the impact of 1^0C temperature shock on per capita income growth across different exchange rate regimes. The last two rows show the impact of a 100-millimeter increase in precipitation on per capita income growth across different exchange rate. Summary statistics are reported for only horizon 5. The sample comprises all countries with annual average temperature greater than 15^0C.*

Mechanisms

This section is motivated by the following question: Why is the initial impact of the weather shocks and the ensuing recovery worse under fixed exchange rate regimes? The standard mechanism in the theoretical literature is that if prices and wages are sticky, then flexible exchange rate regimes can enable a faster real exchange rate adjustment through a nominal depreciation. The change in relative prices between domestic and foreign goods (and services) can prompt a shift in the composition of domestic consumption and investment away from foreign goods and toward domestic goods, while also boosting the demand for exports. At the same time, the pass-through to inflation would lead to higher price levels and reduce real wages and help the adjustment process. In contrast, without monetary autonomy, fixed exchange rate regimes rely primarily on countercyclical fiscal policy to mitigate the impact of adverse shocks. In what follows, during the exploration of the underlying mechanisms, we focus on the temperature shocks because the results are more robust.

The impact of the temperature shocks on inflation is illustrated in **Figure 10** and presented in **Table A9** in the appendix. The figure shows how the change in the inflation rates responds to the shocks under the two regimes. The patterns are broadly similar with inflation trending upward after the initial impact of the shock, suggesting a generally similar degree of prices stickiness. In particular, the results three years after the shock (h=3) are statistically significant. In line with expectations, inflation rises to a slightly greater extent under the floating regimes.

Figure 10: Mechanisms: Inflation
(percentage points)



Source: Authors' calculations.

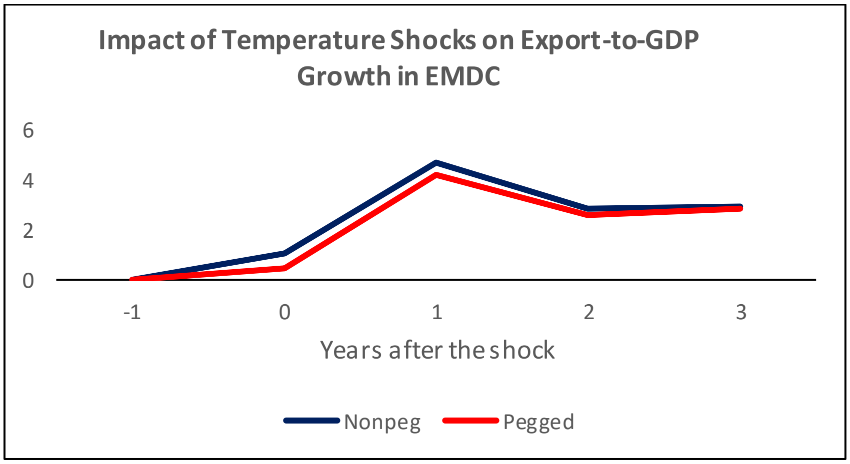
Notes: The figure shows the impact of 1^{0}C increase in temperature on inflation across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^{0}C.

To understand the differences in the output response to the shocks under both regimes, we now investigate the response of exports. The exports-to-GDP ratio is shown in **Figure 11** with the regression results displayed in **Table A10** in the appendix. The figure shows a broadly similar export response under both regimes, which is counterintuitive. We were expecting a stronger pickup in exports under the flexible exchange rate regime.

The ratio of exports to GDP measures the relative importance of the export sector in the overall economy. However, because the temperature shocks can also affect GDP—the denominator of this ratio—these results could possibly reflect the behavior of GDP rather than that of the export sector. Therefore, as an alternative indicator of export performance, we consider the growth in the real value of exports.

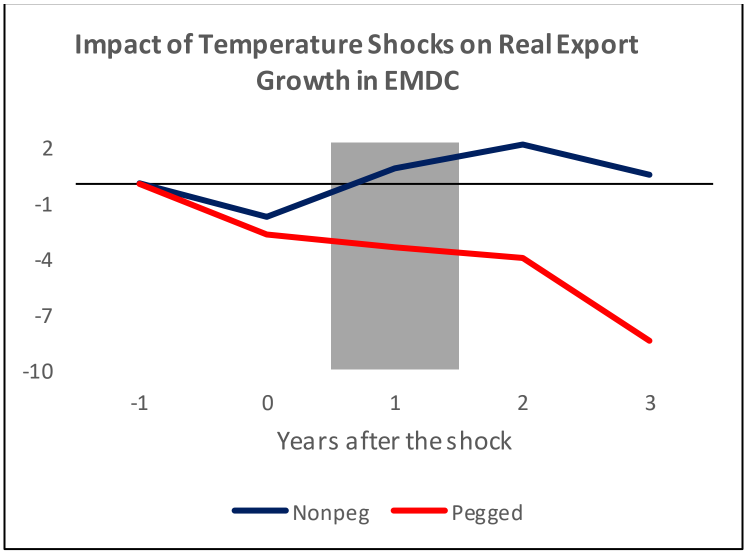
As shown in **Figure 12**, there are significant differences in the response of real export growth under the two regimes. Under a peg, real export growth displays a downward trend. In contrast, under the non-pegged regimes, we see a J-curve-like pattern in the response of real export growth. The estimates indicate that these differences are statistically significant in the first year after the impact of the shock (see **Table A11** in the appendix). While under the floating exchange rate regime real export growth would increase by 0.8 percentage points one year after the shock, the corresponding decline under the peg is –3.4 percentage points. Likewise, the medium-term increase in real export growth is 1.4 percentage points under flexible exchange rate regimes as compared to 5.5 percentage point decline under the pegs.

Figure 11: Mechanisms: Export-to-GDP Ratio
(percentage points)



Source: Authors' calculations.
Notes: The figure shows the impact of 1^{0}C increase in temperature on export growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^{0}C.

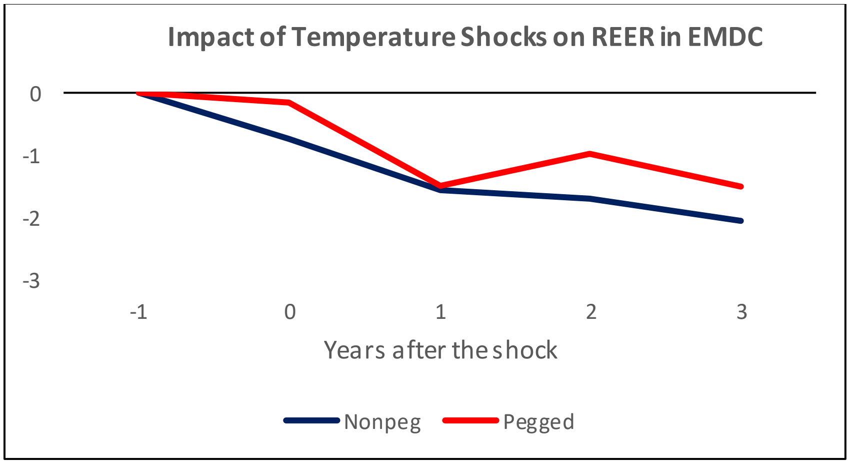
Figure 12: Mechanisms: Real Export Growth
(percent)



Source: Authors' calculations.
Notes: The figure shows the impact of 1^{0}C increase in temperature on real export growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^{0}C.

The patterns of the real effective exchange rate (REER) are also broadly in line with expectations. As shown in **Figure 13**, while the dynamic response indicates real (effective) depreciations under both regimes, the change in this key relative price is more pronounced under the non-pegged regimes (and statistically significant over the medium-term; **Table A12** in the appendix).[3]

Figure 13: Mechanisms: Real Effective Exchange Rate (REER)
(percent)



Source: Authors' calculations.
Notes: The figure shows the impact of 1^{0}C increase in temperature on real effective exchange rate across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^{0}C.

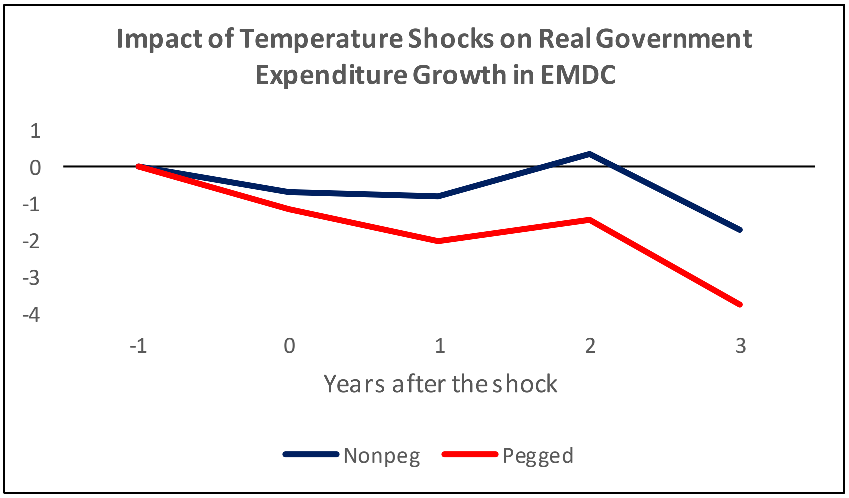
What role for fiscal policy?

Under the textbook Mundell-Fleming framework fiscal policy is an effective stabilization tool under a peg in contrast to the case under a flexible exchange rate regime. We would therefore expect a countercyclical fiscal policy stance in response to the weather shocks. We consider the change in real growth in government expenditures (on goods and services) as our proxy for the fiscal stance. This measure has been advocated by Kaminsky, Reinhart, and Végh (2004) since it is a policy instrument in contrast to the endogenous outcome variables (such as the primary balance to GDP ratio).

---

[3] Exchange rate flexibility can also facilitate adjustment to shocks by affecting the real wage. This channel has been emphasized in recent theoretical work by Schmitt-Grohé and Uribe (2016) who introduce downward nominal wage rigidities into a DSGE model. In this setup, the exchange rate regime plays a particularly important role in determining the response of real variables. In particular, as shown in Carrière-Swallow, Magud, and Yépez (2021), a nominal exchange rate depreciation can lower real wages by decreasing the level of the price of tradable goods, thereby facilitating the adjustment to shocks. Notwithstanding data limitations, which would affect estimation precision, the indicative results suggest that real wages are statistically significant two years after the shocks under a peg relative to the float (See **Table A13** in the Appendix). Other relative prices where are considered, but data limitations were even more of an issue.

Figure 14: Mechanisms: Real Government Expenditure
(percent)

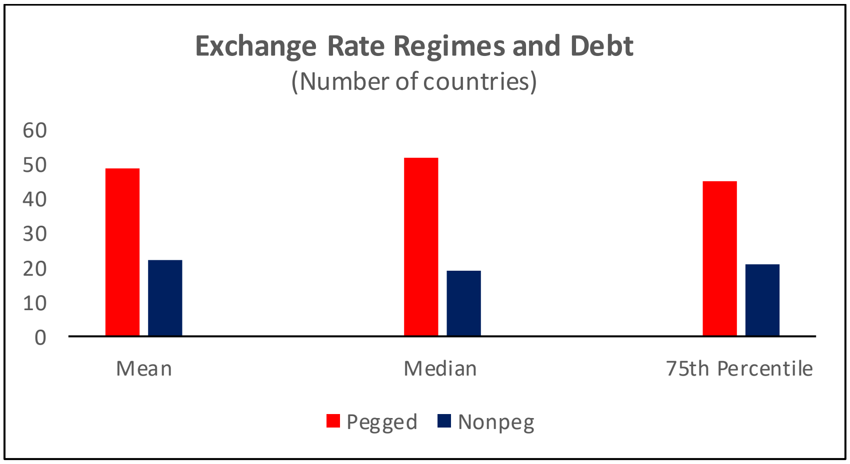


Source: Authors' calculations.
Notes: The figure shows the impact of 1^{0}C increase in temperature on real government expenditure across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h). Gray shaded regions indicate that the coefficients between the pegged and non-pegged regimes are statistically different from each other at that horizon at least at 10 percent significance level. The sample comprises all Emerging Market and Developing Economies with annual average temperature greater than 15^{0}C.

The results are shown in **Figure 14** (and complemented by **Appendix Table A14**). Interestingly, fiscal policy appears to be procyclical under both regimes, which is in line with Kaminisky, Reinhart, and Végh (2004). However, the decline in government expenditure growth is not statistically significant under the flexible exchange rate regimes. A benign interpretation, in this case, could be that fiscal policy is acyclical under more flexible exchange rates. In contrast, the decreases in real government expenditure growth is statistically significant in the first and third years after the shocks indicating a contractionary fiscal stance at these horizons when the exchange rate is pegged. Why is this the case?

One explanation could be fiscal space. Even though fiscal policy is the main macroeconomic countercyclical tool under a peg, a high stock of debt would limit the ability for discretionary spending. As a first past to test this assertion, we count the number of countries in each exchange rate regime depending on whether their debt levels are above or below the sample average. For robustness, we do the same exercise for the median and the 75th percentile. The results are shown in **Figure 15** which indicate that there is a larger number of high-debt countries that implement fixed exchange rate regimes. This suggests that these more indebted countries are less able to implement countercyclical fiscal policy during economic downturns, highlighting the importance of the policy mix and precautionary (fiscal) buffers.

Figure 17: Exchange Rate Regime and Debt Profile.



Source: Authors' calculations.
Notes: The figure shows the number of countries under each regime with debt above the sample mean, median, or 75th percentile.

Concluding Remarks

The results of the preceding analysis provide broad support for the notion that greater exchange rate flexibility can help emerging market and developing countries (EMDCs) better adjust to shocks. We use annual variations in temperature and precipitation (weather shocks) to empirically assess the contrasting theoretical predictions about exchange rate regimes and the adjustment to shocks. We find that greater exchange rate flexibility not only helps mitigate the initial impact of these shocks, but also promotes a faster recovery on average across EMDCs.

The underlying adjustment mechanisms also seem to be generally consistent with that identified in the theoretical literature. For example, real export growth increases throughout the medium term under flexible exchange rate regimes, while it declines under the pegs. Consistent with the adjustment through a depreciation of the nominal exchange rate, there is a significant export response for non-pegged regimes.

Although we would expect a countercyclical fiscal policy stance in response to the weather shocks under pegged regimes, it appears that the prevalence of high debt restrains this macroeconomic stabilization tool. This underscores the importance of the policy mix and precautionary (fiscal) buffers. That is, the choice, and effectiveness, of the exchange rate regime cannot be considered in isolation from other macroeconomic policies.

The role of heterogeneity across countries also needs to be acknowledged. In particular, a fixed exchange rate regime may have advantages over flexible ones for some countries under certain circumstances. Importantly, the adoption of greater exchange rate flexibility should be done to ensure a smooth transition and with a new, credible nominal anchor.

Appendix A

Data Sources and Country Groupings

Table A1: Data sources

Indicator	Sources
Temperature and precipitation	Acevedo and others (2020)
Per capita income	IMF, World Economic Outlook database; World Bank, World Development Indicators database
Exchange rate regimes	Ilzetzki, Reinhart, and Rogoff (2019), Shambaugh (2004) Exchange Rate Regime Classification, IMF Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER)
Real Exports	IMF, World Economic Outlook database; World Bank, World Development Indicators database
Government Expenditure	IMF, World Economic Outlook database; World Bank, World Development Indicators database
Inflation	IMF, World Economic Outlook database; World Bank, World Development Indicators database
Government Debt	IMF, World Economic Outlook database; World Bank, World Development Indicators database
Real Effective Exchange Rate	IMF, World Economic Outlook database; World Bank, World Development Indicators database
Real Wages	International Labor Organization, Real wage database

Table A2: Country Groupings

Countries in the sample	
Advanced Economies	Australia, Austria, Belgium, Canada, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Puerto Rico, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States
Emerging Market Economies	Albania, Algeria, Angola, Antigua and Barbuda, Argentina, Armenia, Azerbaijan, Bahrain, Barbados, Belarus, Belize, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Cabo Verde, Chile, China, Colombia, Costa Rica, Croatia, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Fiji, Gabon, Georgia, Grenada, Guatemala, Guyana, Hungary, India, Indonesia, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Kuwait, Lebanon, Libya, Malaysia, Mauritius, Mexico, Montenegro, Morocco, Namibia, North Macedonia, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Qatar, Romania, Russia, Samoa, Saudi Arabia, Serbia, South Africa, Sri Lanka, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Swaziland, Syria, Thailand, Timor-Leste, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Ukraine, United Arab Emirates, Uruguay, Vanuatu, Venezuela
Developing Countries	Afghanistan, Bangladesh, Benin, Bhutan, Bolivia, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Republic of Congo, Côte d'Ivoire, Djibouti, Eritrea, Ethiopia, The Gambia, Ghana, Guinea, Guinea-Bissau, Haiti, Honduras, Kenya, Kyrgyz Republic, Lao P.D.R., Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Moldova, Mongolia, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Papua New Guinea, Rwanda, Senegal, Sierra Leone, Solomon Islands, South Sudan, Sudan, São Tomé and Príncipe, Tajikistan, Tanzania, Togo, Uganda, Uzbekistan, Vietnam, Yemen, Zambia, Zimbabwe

Table A3: The Impact of Temperature Shocks Over Time

	Per Capita Income Growth: Before 1990		
Horizon	Nonpeg	Pegged	p_value
0	-1.427 *	-1.424 *	0.991
	(0.744)	(0.771)	
1	-0.747	-0.813	0.838
	(1.139)	(1.118)	
2	-0.585	-0.840	0.463
	(1.189)	(1.196)	
3	-0.265	-0.479	0.585
	(1.473)	(1.496)	
4	-1.279	-1.638	0.456
	(1.498)	(1.495)	
5	-0.486	-0.936	0.368
	(1.519)	(1.480)	
Adjusted R2		0.49	
Number of countries		78	
Number of observations		1428	

	Per Capita Income Growth: After 1990		
Horizon	Nonpeg	Pegged	p_value
0	-0.985 **	-1.479 ***	0.124
	(0.387)	(0.462)	
1	-0.508	-1.273 **	0.094
	(0.460)	(0.537)	
2	-0.385	-1.064 *	0.254
	(0.546)	(0.594)	
3	-0.792	-1.341 *	0.423
	(0.695)	(0.752)	
4	-0.813	-1.566 *	0.306
	(0.884)	(0.898)	
5	-0.111	-1.007	0.250
	(0.914)	(0.925)	
Adjusted R2		0.41	
Number of countries		115	
Number of observations		2053	

Source: Authors' calculations.

*Notes: The tables show the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all with annual average temperature greater than 15^{0}C.*

Table A4: The Impact of Precipitation Shocks Over Time

	Per Capita Income Growth: Before 1990		
Horizon	Nonpeg	Pegged	p_value
0	0.201	0.129	0.514
	(0.137)	(0.092)	
1	0.090	0.045	0.717
	(0.143)	(0.109)	
2	0.002	-0.036	0.808
	(0.179)	(0.150)	
3	0.328	0.120	0.216
	(0.214)	(0.183)	
4	0.499 *	0.274	0.216
	(0.273)	(0.226)	
5	0.442 *	0.356	0.614
	(0.261)	(0.251)	
Adjusted R2		0.49	
Number of countries		78	
Number of observations		1428	

	Per Capita Income Growth: After 1990		
Horizon	Nonpeg	Pegged	p_value
0	0.085	-0.162 *	0.143
	(0.096)	(0.096)	
1	0.174	-0.266	0.074
	(0.146)	(0.175)	
2	0.234	-0.218	0.074
	(0.157)	(0.188)	
3	0.236	-0.321	0.046
	(0.162)	(0.202)	
4	0.222	-0.400 **	0.018
	(0.140)	(0.186)	
5	0.262	-0.231	0.069
	(0.167)	(0.240)	
Adjusted R2		0.41	
Number of countries		115	
Number of observations		2053	

Source: Authors' calculations.

*Notes: The tables show the impact of a 100-millimeter increase in precipitation on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all with annual average temperature greater than 15^{0}C.*

Table A5: The Impact of Temperature Shocks on per Capita Income Growth for full set of Countries.

	Per Capita Income Growth: Full Sample				
Horizon	Nonpeg		Pegged		p_value
0	-0.506	***	-0.668	***	0.043
	(0.184)		(0.200)		
1	-0.405	*	-0.630	**	0.069
	(0.229)		(0.259)		
2	-0.308		-0.586	*	0.054
	(0.293)		(0.331)		
3	-0.393		-0.658		0.134
	(0.351)		(0.413)		
4	-0.336		-0.569		0.223
	(0.449)		(0.498)		
5	-0.238		-0.512		0.186
	(0.504)		(0.555)		
Adjusted R2			0.39		
Number of countries			173		
Number of observations			5182		

Source: Authors' calculations.

*Notes: The table shows the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all Emerging Market and Developing Economies.*

Table A6: The Impact of Temperature Shocks on per Capita Income Growth for "Constant Regime".

	Per Capita Income Growth: EMDC				
Horizon	Nonpeg		Pegged		p_value
0	-0.996	**	-1.416	***	0.448
	(0.456)		(0.433)		
1	-0.215		-1.600	***	0.059
	(0.668)		(0.537)		
2	0.008		-1.623	**	0.097
	(0.727)		(0.740)		
3	-0.339		-1.602	**	0.109
	(0.728)		(0.756)		
4	-0.469		-2.273	**	0.120
	(0.935)		(1.107)		
5	0.224		-2.090	*	0.071
	(1.007)		(1.156)		
Adjusted R2			0.35		
Number of countries			110		
Number of observations			3153		

Source: Authors' calculations.

*Notes: The table shows the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all EMDCs with annual average temperature greater than 15^{0}C.*

Table A7: The Impact of Temperature Shocks on per Capita Income Growth using Shambaugh's Classification.

	Per Capita Income Growth: EMDC				
Horizon	Nonpeg		Pegged		p_value
0	-0.824	***	-1.089	***	0.179
	(0.310)		(0.303)		
1	-0.647		-0.958	**	0.166
	(0.433)		(0.394)		
2	-0.767		-1.043	**	0.251
	(0.463)		(0.437)		
3	-1.068	**	-1.329	***	0.398
	(0.429)		(0.483)		
4	-1.299	**	-1.848	***	0.193
	(0.599)		(0.644)		
5	-1.082		-1.442	**	0.255
	(0.743)		(0.701)		
Adjusted R2			0.30		
Number of countries			108		
Number of observations			4950		

Source: Authors' calculations.

*Notes: The table shows the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all EMDCs with annual average temperature greater than 15^{0}C.*

Table A8: The Impact of Temperature Shocks on per Capita Income Growth (3 lags).

	Per Capita Income Growth: EMDC				
Horizon	Nonpeg		Pegged		p_value
0	-1.141	***	-1.546	***	0.085
	(0.352)		(0.344)		
1	-0.631		-1.330	***	0.063
	(0.513)		(0.478)		
2	-0.440		-1.330	**	0.076
	(0.499)		(0.536)		
3	-0.763		-1.703	**	0.127
	(0.568)		(0.651)		
4	-1.151	*	-2.284	***	0.079
	(0.671)		(0.728)		
5	-0.941		-2.184	***	0.060
	(0.656)		(0.766)		
Adjusted R2			0.35		
Number of countries			115		
Number of observations			3252		

Source: Authors' calculations.

*Notes: The table shows the impact of 1^{0}C increase in temperature on per capita income growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all EMDCs with annual average temperature greater than 15^{0}C.*

Table A9: The Impact of Temperature Shocks on Inflation.

	Inflation: EMDC				
Horizon	Nonpeg		Pegged		p_value
0	5.264		4.220		0.616
	(5.264)		(5.203)		
1	6.162		3.661		0.197
	(4.770)		(5.128)		
2	6.837		5.057		0.515
	(4.956)		(5.416)		
3	9.986	**	9.145		0.747
	(4.926)		(5.589)		
4	8.429		5.530		0.273
	(5.988)		(6.283)		
5	12.031	*	12.047	*	0.996
	(6.194)		(7.069)		
Adjusted R2			0.29		
Number of countries			103		
Number of observations			2316		

Source: Authors' calculations.

*Notes: The table shows the impact of 1^0C increase in temperature on inflation across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all EMDCs with annual average temperature greater than 15^0C.*

Table A10: The Impact of Temperature Shocks on Export-to-GDP Ratio.

	Export-to-GDP Ratio: EMDC				
Horizon	Nonpeg		Pegged		p_value
0	1.054		0.478		0.398
	(1.688)		(1.878)		
1	4.673	**	4.186	**	0.470
	(2.034)		(1.895)		
2	2.817		2.569		0.775
	(2.592)		(2.322)		
3	2.948		2.857		0.928
	(2.911)		(2.978)		
4	2.804		2.794		0.994
	(2.598)		(2.939)		
5	2.823		1.705		0.334
	(2.131)		(1.903)		
Adjusted R2			0.11		
Number of countries			101		
Number of observations			2887		

Source: Authors' calculations.

*Notes: The table shows the impact of 1^0C increase in temperature on export growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all EMDCs with annual average temperature greater than 15^0C.*

Table A11: The Impact of Temperature Shocks on Real Export Growth.

	Real Export Growth: EMDC		
Horizon	Nonpeg	Pegged	p_value
0	-1.774	-2.714	0.367
	(1.465)	(1.989)	
1	0.844	-3.404	0.057
	(2.474)	(3.581)	
2	2.119	-4.044	0.108
	(3.355)	(4.297)	
3	0.483	-8.444	0.140
	(4.100)	(6.495)	
4	2.906	-7.985	0.099
	(4.251)	(7.377)	
5	4.005	-6.413	0.121
	(4.288)	(7.414)	
Adjusted R2		0.49	
Number of countries		104	
Number of observations		2282	

Source: Authors' calculations.
*Notes: The table shows the impact of 1^0C increase in temperature on real export growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all EMDCs with annual average temperature greater than 15^0C.*

Table A12: The Impact of Temperature Shocks on Real Effective Exchange Rate.

	Real Effective Exchange Rate (REER): EMDC			
Horizon	Nonpeg		Pegged	p_value
0	-0.447		0.086	0.487
	(0.959)		(0.855)	
1	-1.230		-1.292	0.947
	(1.694)		(1.602)	
2	-1.605		-1.182	0.745
	(1.561)		(1.547)	
3	-1.918		-1.817	0.939
	(1.682)		(1.561)	
4	-2.724	*	-2.434	0.828
	(1.637)		(1.639)	
5	-1.479		-0.826	0.632
	(1.835)		(1.759)	
Adjusted R2			0.40	
Number of countries			114	
Number of observations			2534	

Source: Authors' calculations.
*Notes: The table shows the impact of 1^0C increase in temperature on real effective exchange rate across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all EMDCs with annual average temperature greater than 15^0C.*

Table A13: The Impact of Temperature Shocks on Real Wages

	Real Wages: EMDC		
Horizon	Nonpeg	Pegged	p_value
0	0.465	0.057	0.196
	(0.620)	(0.717)	
1	-0.464	-0.090	0.299
	(0.473)	(0.611)	
2	-0.105	0.592	0.075
	(0.548)	(0.669)	
3	0.081	0.054	0.884
	(0.424)	(0.411)	
4	0.264	0.182	0.657
	(0.505)	(0.528)	
5	0.771	0.100	0.047
	(0.530)	(0.572)	
Adjusted R2		0.66	
Number of countries		79	
Number of observations		701	

Source: Authors' calculations.

*Notes: The table shows the impact of 1^{0}C increase in temperature on real wages across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all EMDCs with annual average temperature greater than 15^{0}C.*

Table A14: The Impact of Temperature Shocks on Real Government Expenditure

	Real Government Expenditure Growth: EMDC			
Horizon	Nonpeg	Pegged		p_value
0	-0.703	-1.189		0.463
	(0.824)	(0.831)		
1	-0.820	-2.013		0.129
	(1.317)	(1.263)		
2	0.339	-1.465		0.172
	(1.225)	(1.570)		
3	-1.725	-3.761	*	0.148
	(1.449)	(2.010)		
4	-0.001	-1.284		0.336
	(1.454)	(1.703)		
5	1.860	0.827		0.423
	(1.762)	(1.946)		
Adjusted R2		0.15		
Number of countries		94		
Number of observations		2638		

Source: Authors' calculations.

*Notes: The table shows the impact of 1^{0}C increase in temperature on real government expenditure growth across the different exchange rate regimes and is obtained by estimating equation (1) separately for each horizon (h); ***, **, *, indicate the statistical significance of each regression coefficient at the 1, 5, or 10 percent level; likewise, p_values indicate whether the coefficients across regimes at each horizon are statistically different from each other. Summary statistics are reported for only horizon 5. The sample comprises all EMDCs with annual average temperature greater than 15^{0}C.*

References

Acevedo, S., Mrkaic, M., Novta, N., Poplawski-Ribeiro, M., Pugacheva, E., & Topalova, P. (2017). The Effects of weather shocks on economic activity: How can low-income countries cope. *World Economic Outlook*.

Acevedo, S., Baccianti, C., Mrkaic, M., Novta, N., Pugacheva, E., & Topalova, P. (2019). *Weather Shocks and Output in Low-Income Countries: The Role of Policies and Adaptation* (No. 19/178). International Monetary Fund.

Acevedo, S., Mrkaic, M., Novta, N., Pugacheva, E., & Topalova, P. (2020). The effects of weather shocks on economic activity: what are the channels of impact?. *Journal of Macroeconomics*, *65*, 103207.

Alesina, A., Özler, S., Roubini, N., & Swagel, P. (1996). Political instability and economic growth. *Journal of Economic growth*, *1*(2), 189-211.

Bluedorn, J. C. (2005). Hurricanes: intertemporal trade and capital shocks.

Bordo, M. D. (2003). Exchange Rate Regime Choice in Historical Perspective. *IMF Working Papers*, *2003*(160).

Box, G. E. P. and Jenkins, G. M. (1976). Time Series Analysis, Forecasting and Control. San Francisco: Holden-Day

Boyanowsky, E. (1999). Violence and aggression in the heat of passion and in cold blood: The Ecs-TC syndrome. *international Journal of Law and psychiatry*, *22*(3-4), 257-271.

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, *527*(7577), 235-239.

Cantelmo, A., Fatouros, N., Melina, G., & Papageorgiou, C. (2022). Monetary Policy in Disaster-Prone Developing Countries.

Carlsmith, J. M., & Anderson, C. A. (1979). Ambient temperature and the occurrence of collective violence: a new analysis. *Journal of personality and social psychology*, *37*(3), 337.

Carrière-Swallow, Y., Magud, N. E., & Yépez, J. F. (2021). Exchange rate flexibility, the real exchange rate, and adjustment to terms-of-trade shocks. *Review of International Economics*, *29*(2), 439-483.

Cavallo, E., Galiani, S., Noy, I., & Pantano, J. (2013). Catastrophic natural disasters and economic growth. *Review of Economics and Statistics*, *95*(5), 1549-1561.

Chinn, M. D., & Wei, S. J. (2013). A faith-based initiative meets the evidence: does a flexible exchange rate regime really facilitate current account adjustment?. *Review of Economics and Statistics*, *95*(1), 168-184.

Dell, M., Jones, B. F., & Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, *4*(3), 66-95.

Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature*, *52*(3), 740-98.

Dornbusch, R. (1976). Expectations and exchange rate dynamics. *Journal of political Economy*, *84*(6), 1161-1176.

Elekdağ, S., & Tchakarov, I. (2007). Balance sheets, exchange rate policy, and welfare. *Journal of economic dynamics and control*, *31*(12), 3986-4015.

Fleming, J. M. (1962). Domestic financial policies under fixed and under floating exchange rates. *Staff Papers*, *9*(3), 369-380.

Frankel, J. A. (2012). Choosing an exchange rate Regime. *J. James, I. Marsh, L. Sarno, Handbook of Exchange Rates, Wiley*, 765-783.

Frankel, J., & Rose, A. (2002). An estimate of the effect of common currencies on trade and income. *The quarterly journal of economics*, *117*(2), 437-466.

Friedman, M. (1953). The case for flexible exchange rates. *Essays in positive economics*, *157*(203), 33.

Gallup, J. L., Sachs, J. D., & Mellinger, A. D. (1999). Geography and economic development. *International regional science review*, *22*(2), 179-232.

Graff Zivin, J., & Neidell, M. (2014). Temperature and the allocation of time: Implications for climate change. *Journal of Labor Economics*, *32*(1), 1-26.

Ilzetzki, E., Reinhart, C. M., & Rogoff, K. S. (2019). Exchange arrangements entering the twenty-first century: Which anchor will hold?. *The Quarterly Journal of Economics*, *134*(2), 599-646.

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: *The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. In Press.

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American economic review*, *95*(1), 161-182.

Kahn, M. E., Mohaddes, K., Ng, R. N., Pesaran, M. H., Raissi, M., & Yang, J. C. (2019). *Long-term macroeconomic effects of climate change: A cross-country analysis* (No. w26167). National Bureau of Economic Research.

Kaminsky, G. L., Reinhart, C. M., & Végh, C. A. (2004). When it rains, it pours: procyclical capital flows and macroeconomic policies. *NBER macroeconomics annual*, *19*, 11-53.

Mundell, R. A. (1961). A theory of optimum currency areas. *The American economic review*, *51*(4), 657-665.

Nordhaus, W. D. (2006). Geography and macroeconomics: New data and new findings. *Proceedings of the National Academy of Sciences*, *103*(10), 3510-3517.

Ramcharan, R. (2007). Does the exchange rate regime matter for real shocks? Evidence from windstorms and earthquakes. *Journal of International Economics*, *73*(1), 31-47.

Sachs, J. D., & Warner, A. M. (1997). Sources of slow growth in African economies. *Journal of African economies*, *6*(3), 335-376.

Schmitt-Grohé, S., & Uribe, M. (2017). Is optimal capital control policy countercyclical in open economy models with collateral constraints?. *IMF Economic Review*, *65*(3), 498-527.

Stock, J. H., & Watson, M. W. (2007). Why has US inflation become harder to forecast?. *Journal of Money, Credit and banking*, *39*, 3-33.

Teulings, C. N., & Zubanov, N. (2014). Is economic recovery a myth? Robust estimation of impulse responses. *Journal of Applied Econometrics*, *29*(3), 497-514.

United States. National Advisory Commission on Civil Disorders, & United States. Kerner Commission. (1968). *Report of the national advisory commission on civil disorders*. US Government Printing Office.

Weitzman, M. L. (2011). Fat-tailed uncertainty in the economics of catastrophic climate change. *Review of Environmental Economics and Policy*, *5*(2), 275-292.

Yang, D. (2008). Coping with disaster: The impact of hurricanes on international financial flows, 1970-2002. *The BE Journal of Economic Analysis & Policy*, *8*(1).

PUBLICATIONS

Weather Shocks and Exchange Rate Flexibility
Working Paper No. **WP/2022/093**