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Currencies in Turbulence: Exploring the Impact of Natural Disasters on Exchange Rates

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Currencies in Turbulence: Exploring the Impact of Natural Disasters on Exchange Rates

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ABSTRACT: This paper investigates the impact of natural disasters on exchange rate movements in different country groups with different exchange rate regimes. Using a panel local projection model with a high-frequency monthly dataset of 177 countries during 1970M1-2019M12, we find that exchange rate movements are more sensitive to natural disasters in emerging markets and developing countries (EMDEs) than in advanced economies (AEs). Furthermore, exchange rate reactions to natural shocks depend on exchange rate regimes adopted by EMDEs. On average, both nominal and real exchange rates could depreciate up to 6 percents two years after the disasters in non-pegged regimes. Our findings suggest that EMDEs with flexible exchange rate regimes would observe a faster recovery through nominal and real depreciations, although they should be mindful about policy implications that may arise from large exchange rate fluctuations caused by natural disaster shocks.

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Content

1. Introduction

Climate change is a threat to mankind. Temperatures are rising. The global average temperature is already 1.1 degrees Celsius higher than the pre-industrial level (IPCC, 2023). Climate change is causing more frequent and more damaging natural disasters in many parts of the world (IPCC, 2014). Understanding the impacts of natural disasters is critical for adaptation and mitigation efforts.

The literature has examined the effects of natural disasters on macroeconomic outcomes. Most studies focus on the impact of natural disasters on economic growth (see Bayoumi et al., 2021; Barone and Mocetti, 2014; Cavallo et al., 2013; Cevik and Jalles, 2023a; Fomby et al., 2013; Lian et al., 2022; Loayza et al., 2012; Noy, 2009; Ramcharan, 2007; Elekdag and Tuuli, 2023). These studies typically find negative impacts of natural disasters on economic growth, although the impacts vary with country characteristics such as development level and institutional quality. Another strand of literature focuses on the impact of disasters on inflation, including works by Kabundi et al., (2022), Cevik and Jalles (2023b), Fratzscher et al., (2020), and Mukherjee and Ouattara (2021). Natural disasters are found to increase inflationary pressure, although its magnitude depends on disaster type and the credibility of the monetary framework. There are also few studies examining the impact of natural disasters on other economic outcomes, such as fiscal outcomes (Noy et al., 2011), international capital flows (David, 2010), and exchange rates (Hale, 2022; Farhi and Gabaix, 2015; Lee et al., 2022).

In this paper, we contribute to a developing strand of literature studying the impact of natural disasters on exchange rates at a monthly frequency. Theoretically, natural disasters affect exchange rate levels through changes in balance of payment needs induced by disaster disruptions to infrastructure, supply chains, and productivity. For example, natural disasters can bring disruptions to infrastructure and hurt exports, such as tourism in small islands (see Rosselló et al., 2020; Jones and Olken, 2010; Osberghaus, 2019). At the same time, disaster relief and reconstruction efforts may require higher imports. As a result, trade balance likely deteriorates due to disaster destruction, causing depreciation pressure on the exchange rates (Strobl and Kablan, 2017). On the other hand, remittances and grants from international donors may rise (Arezki et al., 2024; David, 2010), creating exchange rate appreciation pressure. These effects can lead to fluctuations in exchange rates, which in turn can impact the country’s economic and trading stability, especially when the country has financial vulnerability such as dollarized debt.

Understanding the relationship between natural disasters and exchange rates is helpful for policymakers and investors in assessing the risks associated with certain currencies and economies, especially in disaster-prone countries. First, understanding the impact of natural disasters on exchange rates helps market participants navigate and manage exchange rate volatility effectively, and make informed decisions regarding investment, trade, and risk management strategies. Second, exchange rate fluctuations resulting from natural disasters can affect a country's export competitiveness. A depreciating currency can make a country's exports more competitive in the global market, while an appreciating currency may make exports more expensive, potentially impacting trade balances adversely. Hence, the expenditure switching effect might provide a stabilizing channel to help mitigate the impact of natural disasters on an economy (see Ramcharan, 2007; Elekdag and Tuuli, 2023). Finally, governments and central banks often implement policy measures to mitigate the economic impact of natural disasters. By examining the relationship between natural disasters and exchange rates, policymakers can design appropriate monetary and fiscal policies to support economic recovery, stabilize exchange rates, and manage inflationary pressures.

The literature studying the impact of natural disasters on exchange rates, particularly real (effective) exchange rates, is small but expanding. Farhi and Gabaix (2016) introduced a rare disaster model to explain the disconnect between exchange rates and fundamentals using time-varying disaster risk premiums. They argue that rare but extreme disasters is an important determinant of risk premia in asset markets. Hale (2022) constructed a forward-looking model in which agents update their expectations about future disasters. The model predicts a persistent but relatively small real depreciation because of climate-related disasters for risky countries. Although not focusing on the interaction between disasters and exchange rates, Ramcharan (2007), and Elekdag and Tuuli (2023) argue that real exchange rates depreciate more for non-pegged countries when examining channels of how greater exchange rate flexibility help an economy adjust faster to weather shocks. Strobl and Kablan (2017) studies the impact of tropical cyclone destruction on exchange rates of 17 small islands developing states and find that a flexible exchange rate depreciates to help the economy recover from the deterioration of the current account, but a fixed exchange rate almost remains unchanged after the shock. Meanwhile, the results from Lee et. al (2022) on the impact of global temperature shocks on exchange rates are more mixed with exchange rates in some countries depreciate against the shocks while appreciate in the others.

In this paper, we explore the impact of natural disasters on the exchange rates with a special focus on the role of exchange rate regimes[1] and country characteristics. While some studies have looked into this research topic, most of them either focus on specific type of disasters or on specific country group with limited number of observations. This paper aims to provide a broad picture by using a universal monthly panel data of 177 countries from 1970M1 to 2019M12, dividing into different exchange rate regimes (pegged versus non-pegged) and country characteristics (advanced economies, large emerging markets, low-income countries, small island countries). In addition, we examine the high-frequency (i.e., monthly) responses of exchange rates, while the literature mostly works with annual data. One advantage of the high-frequency analysis is that we can attribute the effect of a natural disaster on exchange rates more accurately. At a lower frequency analysis, such as annual, the effect of a natural disaster could be more likely contaminated by other shocks that

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[1] We use pegged and fixed interchangeably to refer to a pegged exchange rate regime defined in Ilzetzki et. al (2019), while non-pegged, flexible, and float are used interchangeably for a non-pegged exchange rate regime.

happen in the same year. In addition, high-frequency data allows tracking the high-frequency responses of exchange rate over time (in our case, over 24 months after the disaster).

Applying the local projection model, we find that exchange rate movement is more sensitive to natural shocks in EMDEs, especially small islands, than in AEs. Furthermore, exchange rate reactions to natural shocks depend on exchange rate regimes adopted in these EMDEs. Nominal and real effective exchange rates could depreciate up to 6 percent after two years from the shock in non-pegged regimes, while likely appreciate significantly albeit mildly in fixed regimes. Our findings corroborate the literature that a real depreciation would help countries with a faster recovery. Nevertheless, EMDEs who are floating their exchange rates should be aware of potential depreciation pressures, which could be particularly significant during large disasters, and prepare for possible challenges that could arise in terms of debt or financial stability (Asonuma, 2016; Reinhart and Rogoff, 2011).

The remainder of the paper is organized as follows. The next section discusses the methodology and data used in the paper. Section 3 presents our empirical results in the baseline model while results for robustness checks are presented in Section 4. Section 5 concludes.

2. Methodology and Data

2.1 Methodology

To capture the possible impact of natural disasters on exchange rates, we use Jorda (2005)'s local projection method to trace the impulse response function of effective exchange rates (nominal and real) to natural disaster shocks. We also investigate response of inflation to natural disasters to help facilitate a discussion on possible deviation of responses between nominal and real exchange rates. Our baseline regression is as follows:

$$s_{i,t+h} - s_{i,t-1} = c + \sum_{j=1}^{p} \alpha_j \Delta s_{i,t-j} + \beta_1^h D_{i,t} + \beta_2^h peg_{i,t} + \beta_3^h D_{i,t} * peg_{i,t} + \alpha_i + \delta_{t,h} + \varepsilon_{i,t+h} \quad (1)$$

where *i, t*, and *h* denote country, month, and the estimation horizon (from 0, which captures the temporaneous response to a natural shock happened at 0, and response up to 24 months ahead). $s_{i,t}$ denotes the log form of the dependent variables, namely the nominal effective exchange rate (NEER), the real effective exchange rate (REER), and the consumer price index (CPI). $\Delta s_{i,t-j}$ denotes the lags of changes of dependent variables up to *j* lags (with *j*=2 in the baseline). $D_{i,t}$ is our main variable of interest – a dummy for natural disasters – which takes value of 1 if a disaster occurs at month t and 0 otherwise. $peg_{i,t}$ denotes the dummy for exchange rate regimes, taking value of 1 if a country adopts a pegged exchange rate regime, and 0 if non-pegged. We control for a country's time-invariant characteristics by the country fixed effect α_i, and for global effects by the month fixed effect $\delta_{t,h}$.

Our main interest coefficient, β_3^h, measures the difference of exchange rate reaction to natural disasters by regimes. Consider right after a disaster strikes at $h = 0$, the exchange rate depreciation rate $(s_{i,t} - s_{i,t-1})$ would be β_1^0 for non-pegged regime and $(\beta_1^0 + \beta_3^0)$ for pegged regime. Statistically significant β_3^h indicates that exchange rates response differently in different exchange rate regimes.

Our baseline model's specification is intentionally parsimonious for several reasons. First, since natural disasters occur randomly and are largely exogenous to local economic conditions, omitting variable bias or endogeneity when using a parsimonious model should not be a strong concern. Indeed, we might want to mitigate overcontrolling bias (Elekdag and Tuuli, 2023; Lee et al., 2022). Second, many of the determinants of exchange rates, such as economic growth, interest rate differentials, international reserves, financial market reaction, may themselves correlated with natural disasters if the shocks trigger a change in monetary policy or change in investor sentiment and are thus not part of the baseline estimation. Third, data for many macroeconomic variables are not readily available at the monthly level. Including them would have the cost of a much-reduced sample size, affecting the representativeness of our findings. Our robustness checks in section 4 will delve into this issue more. Finally, global factors possibly affecting the exchange rates such as changes in monetary environment in large economies, global volatility, are captured by the time fixed effects.

Nevertheless, we conduct a robustness check by expanding model (1) to include additional control variables as below:

$$\begin{aligned} s_{i,t+h} - s_{i,t-1} = c + \sum_{j=1}^{p} \alpha_j \Delta s_{i,t-j} + \beta_1 D_{i,t} + \beta_2 peg_{i,t} + \beta_3 D_{i,t} * peg_{i,t} \\ + \textstyle\sum_{j=1}^{q} \gamma_j X_{i,t-j} + \alpha_i + \delta_{t,h} + \varepsilon_{i,t+h} \end{aligned} \tag{2}$$

where $X_{i,t}$ is a set of control variables including interest rate differentials, and changes in capital account openness, and changes in international reserves. To avoid potential correlation with the natural disasters, all of these control variables are used in lag terms up to *q* lags (with *q*=1 in this paper).

2.2 Data

We restrict data in our study from 1970 to end of 2019 and drop data after 2019 to avoid the volatile years of COVID-induced crisis and recovery. Data on natural disasters are from the AFDA/CRED

International Emergency Disasters Database (EM-DAT), which provides worldwide coverage on the occurrence of natural disasters with detailed information on disaster type, occurrence dates, total number of dead, injured, and affected people, and total damage cost measured in USD. During 1970-2019 period, there were 4,408 disasters worldwide reported in the dataset, with a majority of them (82.9 percent) lasted within a month, while 99.5 percent ended within a year. To access the impact of disasters and remove potential noises from small disasters, we decide to keep disasters with total damage cost equal or larger than 0.1 percent GDP.[2,3] The total damage cost is the amount of physical damages to the country's property, crops, and livestock (EM-DAT) and does not include human loss or reconstruction cost. This leaves us with 1,132 disasters, of which 83.0 percent is climatic events such as drought, flood, storm, and extreme temperature, and the remaining geological events such as volcanic activity, earthquake, landslide, and wildfire (following the classification by Raddatz, 2007 and David, 2010). We also remove disasters lasted more than 12 months (16 disasters) by dropping the whole disaster period from the dataset as they might have different transmission mechanism. This also ensures these periods with prolonged disasters do not fall into the control group. Figure 1 shows the distribution of disasters considered in the baseline model over time and continents. We then construct monthly data of natural disasters based on information of their start dates and end dates and create a monthly dummy variable taking value of 1 if a disaster happened in this month and 0 otherwise. For natural disasters happened for more than a month and up to 12 months, the monthly dummy variable will take value 1 for all the months of the disaster period.

For exchange rates, we utilize a comprehensive dataset of Nominal and Real Effective Exchange Rate (NEER/REER) provided by Darvas (2012, 2021). The International Monetary Fund (IMF) also publishes monthly data for effective exchange rate in its International Financial Statistics (IFS) database, but its country coverage is more limited for shorter time horizon, with only the nominal EER available. Meanwhile, the Darvas dataset provides monthly data for NEER and REER for 178 countries and could go back up to 1960 and is highly correlated with the corresponding data published by the IMF, making it a valuable alternative source for exchange rate data. Table 1 and Appendix Figure 1 provides more insights in comparison of the NEER between Darvas and IMF IFS dataset. In our baseline regressions about the impacts of natural disasters on NEER and REER, we restrict the sample to countries and months that have both NEER and REER.

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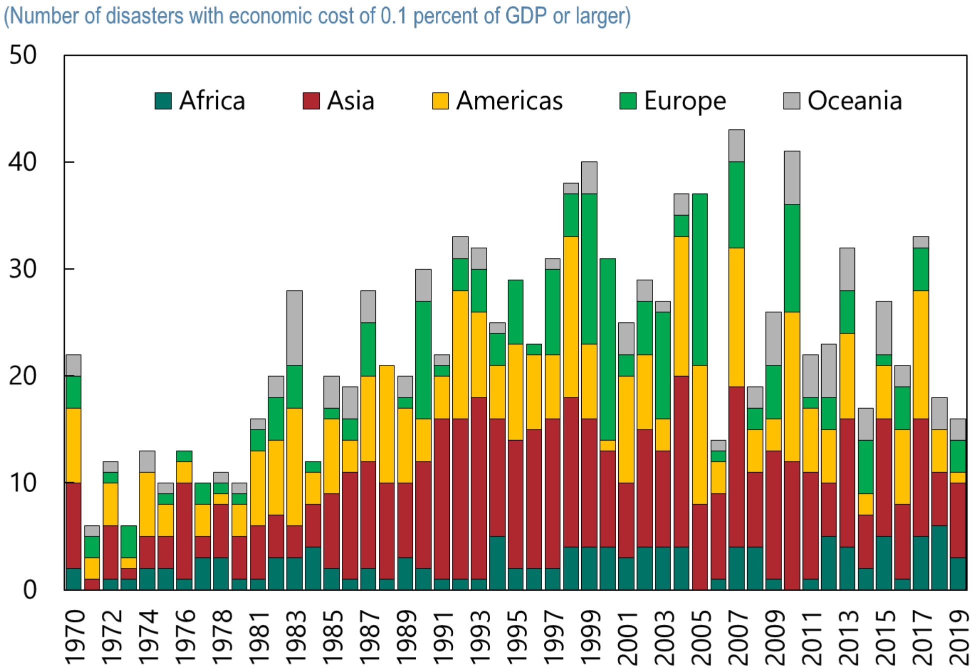
[2] Noy (2009), Fratzscher et al., (2020) suggests reducing the number of events to focus on 'the economic adjustment process to real shocks that are of national economic relevance' and to 'eliminate noise in the reporting of disasters.'

[3] We alternate threshold levels as part of robustness check to include only disasters with economic cost equal or larger than 1 percent of GDP. We confirm that the exchange rate responses are similar but stronger than the baseline. While not reported in this paper, the results are available upon request.

Figure 1: Distribution of Natural Disasters over Time and Continents



Sources: EM-DAT, authors' calculations.

Table 1: NEER data in Darvas dataset and IMF IFS dataset

Country group	Data	No. of observations	Mean	Standard Deviation	Min	Max	Correlation
AEs	*lifs_neer*	14,821	4.63	0.51	2.69	12.14	0.93
	lneer	20,241	4.63	0.84	3.11	13.74	
EMDEs	*lifs_neer*	31,836	5.33	2.24	-0.89	29.79	0.89
	lneer	78,482	5.84	3.54	-14.35	37.96	

Note: *lifs_neer* and *lneer* denote for natural logarithm of NEER from IMF IFS dataset and Darvas dataset, respectively.

Souces: Darvas, IMF IFS, and author calculations.

One of our key variables is exchange rate regime. The IMF publishes information on *de-facto* exchange rate regimes in its Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER). However, since the report started from 1999, we use alternative exchange rate regime dataset from Ilzetzki et. al (2019) to maximize the data coverage. The study refines the classification method of Reinhard and Rogoff (2004) by proposing an algorithm allowing for the possibility of multiple currency poles. Correspondingly, the authors divide the *de-factor* exchange rate regimes and its volatility into 6 coarse categories (or 15 fine categories), ranging from no separate legal tender, pre-announced peg, currency board arrange, to crawling band, managed float, and free floating. We construct a regime dummy take value of 1 (pegged regime) for coarse classification of 1 and 2, ranging from no separate legal tender up to de-facto crawling band within +/-2 percent; and 0 (non-pegged regime) for coarse classifications ranging from 3 to 6. We also follow Ramcharan (2007) and remove countries classified as 5, freely falling, as these countries experience very high inflation (over 40 percent per annum) and possibly large depreciation regardless of their intended exchange rate regimes.[4] Since Ilzetzki et. al (2019) dataset ends in 2019, and 2020 is the start of the COVID pandemic, which might have largely driven exchange rates during those turbulence time, we decide to exclude the period after 2019 from our data. The final dataset includes 177 countries with monthly data from 1970 to 2019.

For other variables, we utilize the consumer price index (CPI) data provided by Ha et al., (2021) as a one-stop source for a global database of inflation; the capital account openness from Chinn and Ito (2006), and policy rates compiled by Haver Analytics. Interest rate differentials are calculated as the difference between the policy rates of the home country with the base country, specified in Shambaugh (2004) paper. Monthly international reserves are available from the International Reserves and Foreign Currency Liquidity (IRFCL) of the IMF. Appendix Table 1 provides descriptive statistics of all variables in our dataset.

3. Empirical Results

3.1 All disasters

Nominal exchange rates

Figure 2 shows the cumulative effects of changes in NEER to all natural disasters, obtained from the baseline regression (1). The dash line shows the point estimations of coefficient β_1^0 for non-pegged exchange rate regime while the solid line shows the point estimations of ($\beta_1^0 + \beta_3^0$) for pegged exchange rate regime. Panel A reports results for all countries. Countries adopting pegged exchange rate regimes observe a significant nominal exchange rate appreciation of 1 percent over two years. In contrast, nominal exchange rates in countries with non-pegged exchange rate regimes depreciate by 4 percents over the same time horizon. Furthermore, the interaction coefficients are statistically significant at 5 percent level for the last 9 periods, implying a stark difference of exchange rate reaction to natural disasters between the two regimes.

To investigate the possible difference between advanced economies (AEs) and emerging and developing economies (EMDEs), we run regression (1) for AEs and EMDEs separately and report

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[4] See Appendix Table 2 for details.

the results in Panels B and C of Figure 2, respectively. It is clear that the aggregated results are mainly driven by results of EMDEs: non-peggers witness a statistically significant nominal depreciation of 6 percents two years after a disaster shock, while peggers nominal exchange rates appreciate 2 percents toward 24 months after a shock. Interaction terms are strongly significant from the 11th month after the shock, suggesting the choice of exchange rate regimes influence the way disasters effect the exchange rate levels in EMDEs. For AEs, the magnitude of exchange rate responses in both regimes is considerably smaller compared to EMDEs and neither the estimated coefficients nor the interaction terms are statistically significant.

Real exchange rates

On the real side, REER responses to natural disasters are insignificant for both regimes for all countries (Figure 3, Panel A). When splitting into country sub-groups, REER in EMDEs countries (Figure 3, panel B) significantly depreciates 5 percents in non-pegged regimes and a mildly appreciates 1 percent in pegged regimes. For AE countries (Figure 3, panel C), the results suggest a mild (statistically insignificant) real appreciation of 2 percents for countries adopting non-pegged regimes and a muted real exchange rate impact for countries with pegged regimes. However, the interaction terms are insignificant, implying that REER response to natural disasters are regime-independent in AEs.

The results are largely in line with the literature, supporting the finding of weaker currencies in non-pegged exchange rate regimes than pegged exchange rate regimes after a weather shock in developing countries. Ramcharan (2007) uses an unbalanced annual panel of 55 developing countries from 1961-2000 to examine the responses of growth in GDP per capita and exports in fixed and flexible exchange rate regimes. He finds that countries with flexible rate regimes recover more quickly with higher per capita GDP growth and higher real export growth compared to countries with fixed rate regimes and argues that flexible exchange rate regimes help country weather the natural disaster shocks better. Interestingly, he did not directly test for possible exchange rate changes in fixed regimes after the shock. Elekdag and Tuuli (2023) also advocate that flexible rate regimes helps mitigate the impact of a climate shock (measured by temperature changes) and promote a faster recovery (in terms of per capital income growth) thanks to the depreciation of real exchange rates. In this regard, our findings suggest that EMDEs adopting fixed exchange rate regimes could be in a slight disadvantage as both of their real and nominal exchange rates did not depreciate after the natural disaster shock.

In addition, we contribute to the literature by providing evidence of differences in responses between country groups. While previous studies argue it is desirable to have exchange rate depreciates after a disaster for higher export competitiveness, the responses of both NEER and REER in EMDEs after a natural shock are far larger than in AEs, raising concerns of exchange rate volatility and uncertainty in the economy. Especially, given a strong link between depreciation and inflation in

EMDEs,[5] having a large depreciation might lead to higher domestic inflation, amid stronger demand of reconstruction and/or limited supply due to infrastructure destruction. Thus, while a real depreciation could help boost the recovery, it could also do the harm if letting inflation goes unchecked. To test this hypothesis, we go a further step of checking the impulse response of consumer price index (CPI) or inflation to disaster shocks using equation (1). The results are reported in Figure 4.

The results so far confirm the presence of price stickiness, with inflation largely unchanged for most of the cases, especially for flexible exchange rate regimes. The changes in prices are very muted compared to the fluctuations in exchange rates. We do not see the depreciation in flexible rate regimes trigger a higher inflation, at least in the short run.

3.2 Disaster types

Climate change is causing more frequent and damaging climate-related natural disasters. Because of the interest, we additionally examine the effects of climate-related natural disasters on exchange rates. We follow Raddatz (2007) and David (2010) and divide disasters in EM-DAT into 2 types: climatic events (drought, flood, storm, and extreme temperature) and geological events (volcanic activity, earthquake, landslide, and wildfire), and investigate the possible different impact of those events on exchange rates.[6] To do so, we create a dummy for each event and incorporate both of them in equation (1), alongside with their interactions with exchange rate regime dummy. The results for each event types are reported by country group for NEER and REER in Figure 5 and Figure 6, respectively.

Given the lion share of this type in all disasters, it is intuitive to find similar results of climatic events compared to all events. We find a depreciation in nominal rates at 5 percents two years after the shock for countries with non-pegged regimes, led by a nominal depreciation of 7 percent in EMDEs and an insignificant nominal change in AEs (Figure 5). For countries with pegged regimes, a nominal appreciation of 1 percent is observed, coming from a 2 percent nominal appreciation in EMDEs and 2 percent nominal depreciation in AEs. It should also be noted that the interaction terms are significant in all country groups, implying a meaningful difference in impact of climatic disasters on the nominal exchange rates by regimes.

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[5] Exchange rate pass-through in EMDEs are found stronger than in AEs in vast literature, likely due to higher inflation environment and menu cost, higher exchange rate volatility, and less credible monetary policy (Taylor, 2000; Campa and Goldberg, 2005; Choudhri and Hakura, 2006; Lopez-Villavicencio and Mignon, 2017)

[6] Since climate change and climatic event such as flood and drought could increase the incidence of landslides and wildfires, we conduct a robustness check by reclassifying landslides and wildfires from geological to climatic events. The results, presented in Appendix Figures 2 and 3, are similar to the baseline.

In terms of real exchange rates, only results for non-pegged regimes are significant and pointing toward a large real depreciation of 4 percent and 7 percent for all countries and EMDEs, respectively, and a mild real appreciation of 2 percent for AEs. In short, we confirm the findings that (1) non-pegged EMDEs witness an exchange rate depreciation in both nominal and real terms after a climatic shock, while pegged EMDEs do not observe highly significant impacts; and (2) impacts on the exchange rates in EMDEs are larger compared to those in AEs.

Meanwhile, exchange rate responses to geological events follow a distinguished pathway. The impact is insignificant in most cases, and furthermore, none of the interaction terms is significant for geological events, indicating the impact of geological shocks on exchange rates is similar (and insignificant) for both regimes for all country groups.

3.3 Country Characteristics

The impact of natural disasters on small island economies receives much attention because small islands' economies are more dependent on exports, such as tourism, and imports. Hence, the effect of exchange rate fluctuations on domestic prices and the economy's stability can be more severe.

This extension examines the impact of natural disasters on exchange rates of three groups of countries, namely low-income countries (LICs), small-island EMDEs, and larger middle-income countries (EMDEs excluding LICs and small islands). Results shown in Figure 7, left-hand side column, indicate that the impact on small islands with non-pegged exchange rate regimes is largest among the three country groups. Small islands' nominal exchange rates (NEER) show a more immediate depreciation (of about 10 percent 8 months after a natural disaster). It is probably because the impact of natural disasters on small islands' exports (specifically, tourism) and imports are larger than other country groups. For larger middle-income countries with non-pegged regimes, the impact of natural disasters on NEER is smaller and more delayed. The depreciation does not reach 10 percent until the end of the second year after disasters. In contrast, for low-income countries, the nominal exchange rate appreciates slightly.

The impact of natural disasters on the real exchange rates (REER) on small islands is more muted (see Figure 7, right-hand side column). This is possible because of the high degree of pass-through from the nominal exchange rates to domestic prices in small islands. A depreciated nominal exchange rate, coupled with rising domestic prices due to high pass-through, could mean that REER might not change much. In contrast, REER shows real depreciation for larger middle-income countries.

We also extend the examination to agriculture-intensive and tourism-dependent countries as those countries could be more prone to natural disasters should agriculture production and tourism revenue respond substantially to natural shocks. To decide whether a country is agriculture-intensive or not, we deploy the data on agriculture, forestry, and fishing, value added as percent of GDP from the World Development Indicator (WDI) database (World Bank). For each year, we define a country to be “agriculture-intensive” if its share of agriculture in GDP is larger than the 75 percentiles of all countries in that year. To remove fluctuation when conducting regressions, we then create a time-invariant dummy for agricultural intensive country, which takes value of 1 if a country has at least 10 years during the 1970-2019 period labelled agriculture intensive. We further remove advanced countries or upper middle-income countries if they are in the ‘agriculture intensive’ list as their agriculture might acquires more advanced technology and more resilient to disasters. The final list includes 47 countries, reported in Appendix Table 3.

A similar approach is used for tourism, in which we use the data of inbound tourism expenditure over GDP published by the United Nation World Tourism Organization (UNWTO) as an indicator for tourism dependency. We initially define a country to be ‘tourism country’ in a year if it was among the top 25 percent countries world-wide received largest inbound expenditure (as percent of GDP) for that year. Since the UNWTO data has shorter period from 1995 to 2019, we define a country as tourism dependent if it had at least 5 years labeled as tourism country during the period. We further exclude large countries from the list and only consider small islands for this exercise. The reason behind is for large countries with several tourism hot spots, it is relatively easy for tourists to ‘replan’ to a different tourism location in the same country if a specific region is hit by a disaster. Therefore, the impact on export could be less visible than small islands. Appendix Table 3 reports the list of 19 small islands that are tourism dependent according to our definition.

The findings for agriculture-intensive countries and the tourism-dependent small islands are shown in Figure 8. Agriculture intensity seems not to influence the exchange rate response to natural disasters. We confirm an insignificant response in countries with flexible exchange rate regimes and a mild nominal appreciation for countries with pegged regimes. However, a tourism-dependent small island sees a large nominal depreciation of the exchange rate after the disasters if the country adopts a flexible exchange rate regime, a similar result to the general small islands group. Interestingly, real exchange rate of this group in fact appreciates and could go up to 7 percent two years after a disaster, much higher than small islands EMDEs. The deviation from small islands EMDEs findings potentially implies either a higher exchange rate pass-through from nominal exchange rate depreciation or a limited scope of keeping inflation in those tourism-dependent islands, whose domestic industry might have further limited production capacity due to high concentration on tourism.

3.4 The impact of larger versus smaller natural disasters

Is the impact on exchange rates driven by large disasters? We are interested in this question because intensifying climate change could increase the scale of natural disasters over time. We examine this potential uneven effect with the following approach. We consider disasters that have economic cost of top 25 percentiles or above as large disasters. We run regression (1) incorporating two disaster dummies: one for large disasters and one for smaller disasters. The baseline group is periods without any disasters. Figures 9 and 10 show the results for NEER and REER cumulative impulse responses, respectively.

The results In Figures 9 and 10 confirm that the impacts of large disasters on nominal and real exchange rates for countries with non-pegged exchange rate regimes are much larger than those of smaller disasters. After large natural disasters, NEER of countries with non-pegged exchange rate regime depreciates up to 15 percent over 24 months, while NEER fluctuations are much more muted after smaller disasters (Figure 9). Similarly, after large natural disasters, REER of countries with non-pegged nominal exchange rate regime depreciates up to 10 percent over 24 months, while REER fluctuations are more muted after smaller disasters (Figure 10). The findings suggest that the larger natural disasters have outsized effects on exchange rates. If natural disasters are increasing in scale due to intensifying climate change, the findings can be concerning.

4. Robustness Check

In our robustness checks, we control other factors that might influence the exchange rate growth such as capital account openness, interest rate differentials, and changes in international reserves.

In the first robustness check, we include pre-disaster lags of change in capital account openness and interest rate differential between home and the base country. A relative open capital account could induce larger capital flows and higher exchange rate volatility, while changes in monetary policy either in home country or the base country would likely influence the exchange rate levels due to interest parity theory. However, there could be a correlation between changes in monetary policy, and to a lesser extent capital account openness, due to natural disasters. In other words, multicollinearity could be a concern if contemporaneous terms of interest rates or capital account openness are added. Therefore, we decide to incorporate the (pre-disaster) lags of these variables to capture any possible changes in policy *before* natural disasters that might have lingering effect on exchange rate levels. The findings are shown in the left column of Figure 11.

Note that data of interest rates are not available for many countries during the estimated period. There are 36,874 observations (country-month) with real interest rate differential data versus 86,121 observations with REER data (see Appendix Table A1). To be able to compare the robustness check's findings with those from the baseline model, we restrict the sample of the baseline model to that with the same data coverage. The results from the baseline model with the same data coverage as the robustness check model is shown in the right column of Figure 10 for comparison.

The results in both columns of Figure 11 are similar to each other, but slightly different from the baseline model with the unrestricted sample. This proves that our parsimonious model is robust in terms of bias estimation, since including other control variables do not alternate the results as long as the sample remains the same. In another words, estimation with interest rate data to some extent could suffer from sample selection bias as countries without interest rate data are likely low-income countries. Comparing carefully, the results for AEs are similar to the baseline regression, but results for EMDEs are considerably different, corroborating the argument of sample selection bias regarding data in less developed countries.

We conduct another robustness check and include international reserves data on top of the first robustness model. Similar to interest rate differential and capital account openness, foreign intervention is an important exchange rate determinants but might suffer from high correlation with the natural disaster variable if contemporaneous terms are included. Therefore, we also incorporate a lag of changes in reserves to capture lingering effect of previous intervention on exchange rate levels. Furthermore, we re-run the baseline model with the new sample as number of observations with available international reserves data only accounts for *20 percent* of total observations in the baseline. Figure 12 shows the results of the robustness model with three additional control variables in the left column, and the baseline model with the same data coverage as the robustness model in the right column. We confirm that the results of the robustness model and the parsimonious model with the same sample are similar to each other, but different from the baseline model with the unrestricted sample, suggesting a possible sample selection bias arising from data availability.

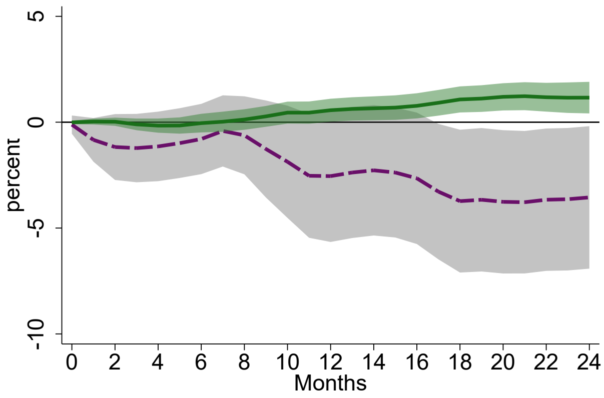
5. Concluding Remarks

In this paper, we investigate the impact of natural disaster on exchange rate movements in different country groups and different regimes by applying the local projection model for a universal monthly dataset of 177 countries during the 1970-2019 period. Our paper is among the first papers to investigate the topic using high-frequency data rather than annual or quarterly data. Our findings are three-folds. First, exchange rate movements are more sensitive to natural shocks in EMDEs than in AEs. Our empirical tests largely point to an insignificant reaction of both nominal and real exchange rates to disasters in AEs. Meanwhile, exchange rates in EMDEs react significantly to disasters shocks, indicating the sensitivity of the market to natural disasters. Second, exchange rate reactions to natural disaster shocks depend on exchange rate regimes. While the choice of regimes does not play a role in how the exchange rates react to natural shocks in AEs, the regimes play a significant role in differentiating the way exchange rates respond in EMDEs. The exchange rates could depreciate up to 6 percent two years after the shock in float regimes, while appreciate mildly in fixed regimes. Finally, exchange rates of small island economies are more sensitive to natural disasters, and larger disasters have stronger impacts on exchange rate fluctuations in general.

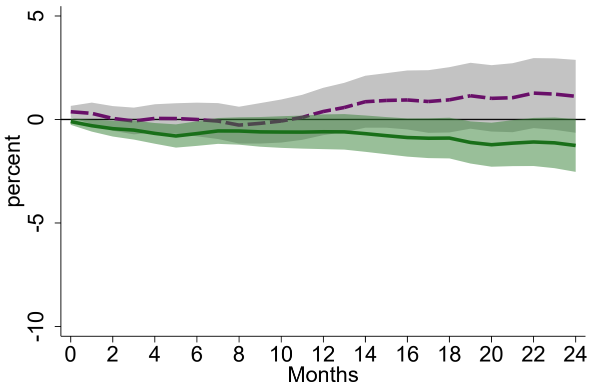
Our findings suggest that EMDEs should be prepared for possible exchange rate fluctuations after natural disasters hit. It is generally agreed that a real depreciation would help countries with a faster recovery after the shocks via expenditure switching, and thus, a floating exchange rate regime could be more desirable (also see Elekdag and Tuuli 2023). Also, price stickiness, as confirmed in our paper, would help lower the risk of higher imported inflation due to exchange rate depreciation in the short run. Nevertheless, EMDEs floating their exchange rates should be aware of feasible depreciation pressure, which could be particularly significant during large natural disasters. At the same time, they should prepare for possible policy challenges arising in terms of debt or financial stability, especially when financial vulnerabilities such as dollarized debt or currency mismatch are present (also see Reinhart and Rogoff, 2011; Asonuma, 2016). Similarly, disaster-prone EMDEs with intention to open their capital account and moving to a more flexible exchange rate should be mindful about the additional exchange rate fluctuation coming from natural shocks. In this regard, the results of this paper could be helpful when building scenario-based macro-framework in disaster-prone countries, taking into account disaster-led exchange rate fluctuation.

Finally, as data and technical limitations remain in this paper, additional questions regarding this topic should be investigated further in future research. They include a possible sample bias when incorporating interest rates or other control variables, the mechanisms behind exchange rate movements after disasters, and the possible heterogeneity among prerequisite macroeconomic condition and policy reaction post-disaster such as inflation, interest rate, international reserves, that could influence the way exchange rates respond to natural shocks.

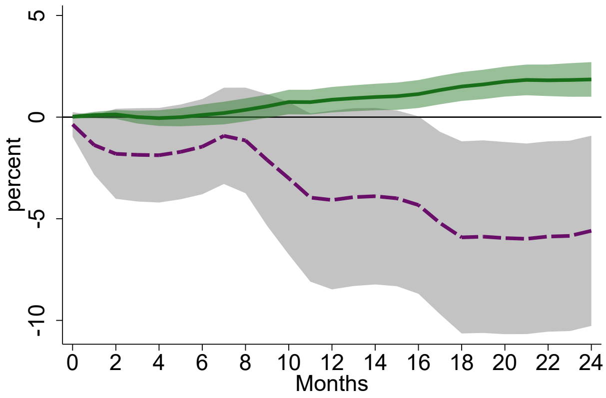
Figure 2: Cumulative Impulse Responses of NEER to Natural Disasters during 1970-2019



(A) All Countries



(B) Advanced Countries



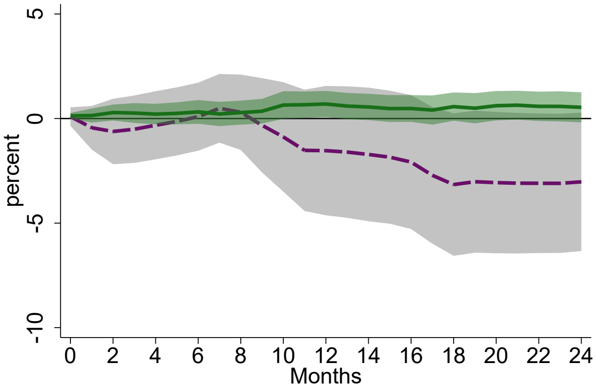
(C) Emerging Market and Developing Countries

Note: The figure shows the cumulated response of NEER to natural disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of NEER implies an exchange rate appreciation (depreciation).

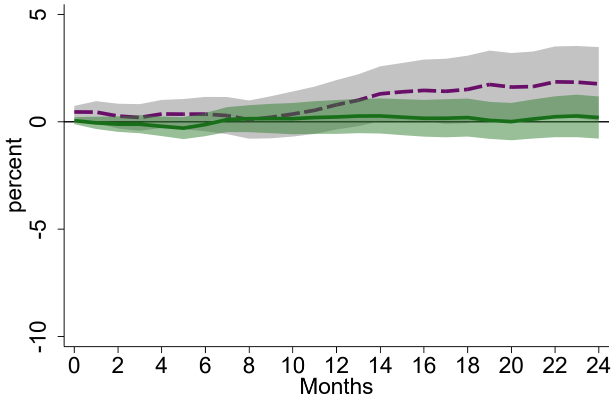
Source: Authors' calculations.

Figure 3: Cumulative Impulse Responses of REER to Natural Disasters during 1970-2019

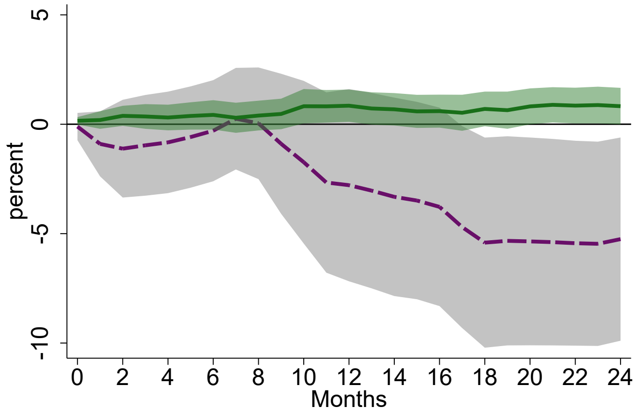
(A) All Countries



(B) Advanced Countries



(C) Emerging Market and Developing Countries

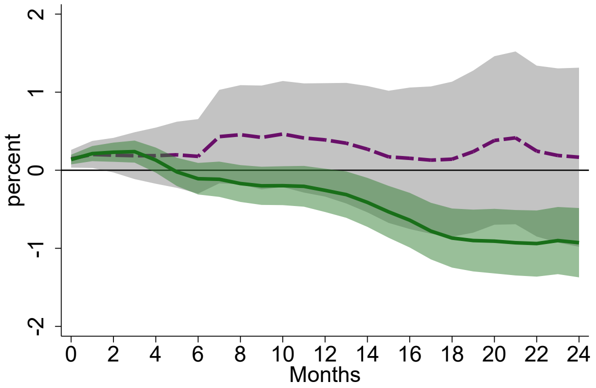


Note: The figure shows the cumulated response of REER to natural disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of REER implies an exchange rate appreciation (depreciation).

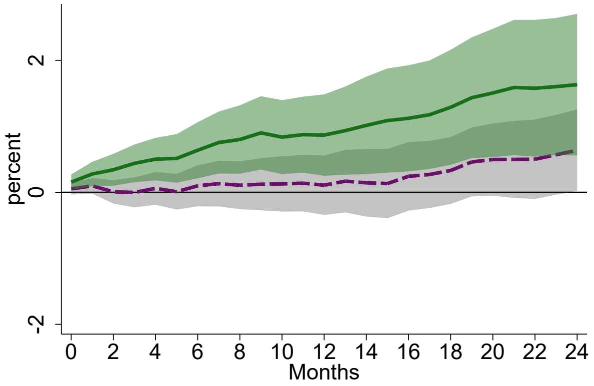
Source: Authors' calculations.

Figure 4: Cumulative Impulse Responses of CPI to Natural Disasters during 1970-2019

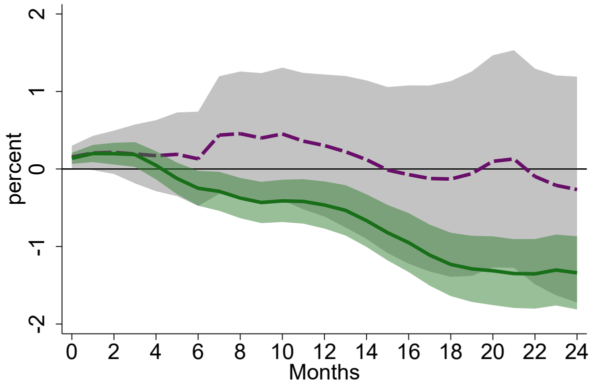
(A) All Countries



(B) Advanced Countries



(C) Emerging Market and Developing Countries

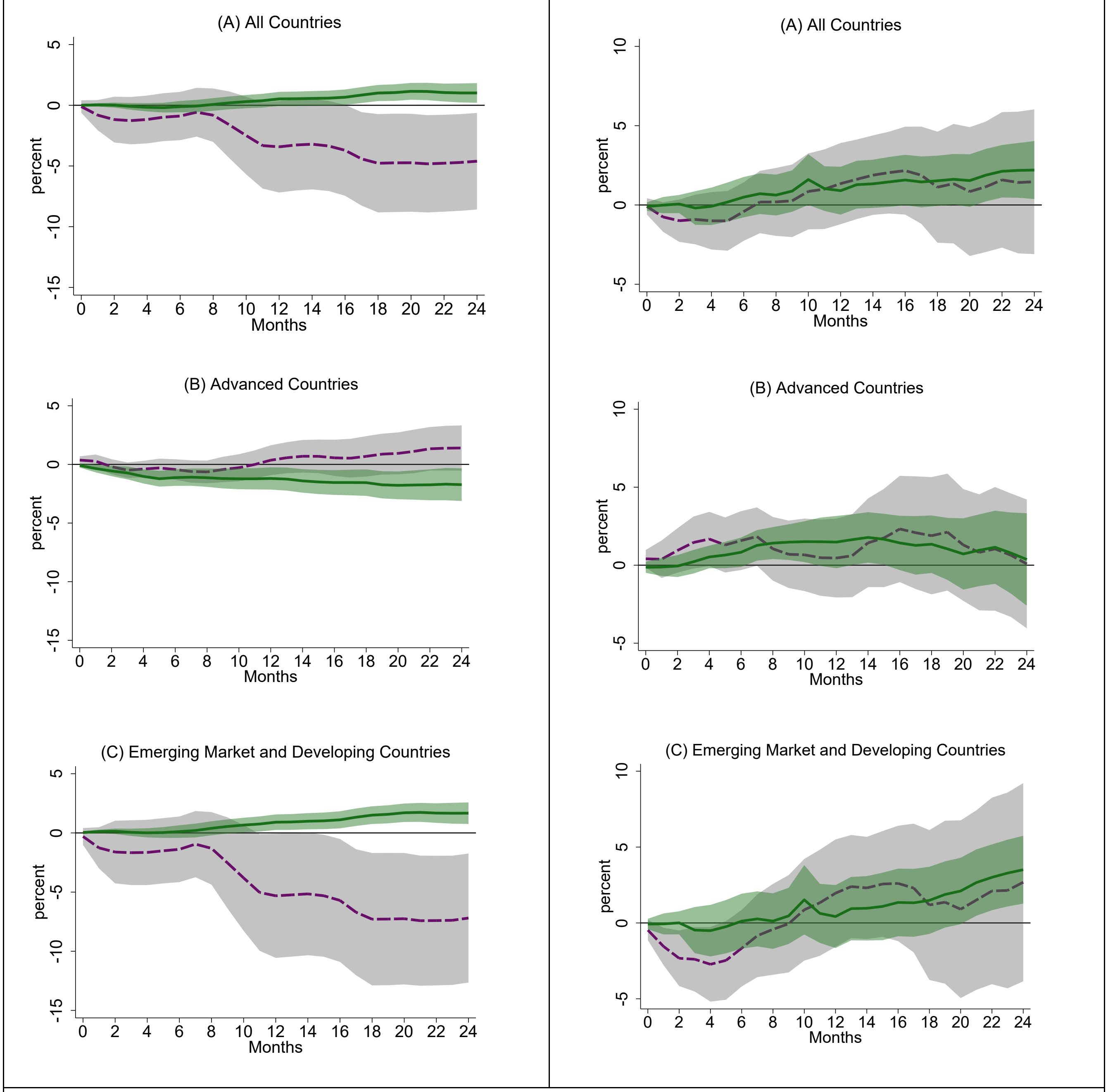


Note: The figure shows the cumulated response of inflation to natural disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes.

Source: Authors' calculations.

Figure 5: Cumulative Impulse Responses of NEER to Disaster Shock by Disaster Type, 1970-2019

Climatic events | Geological events

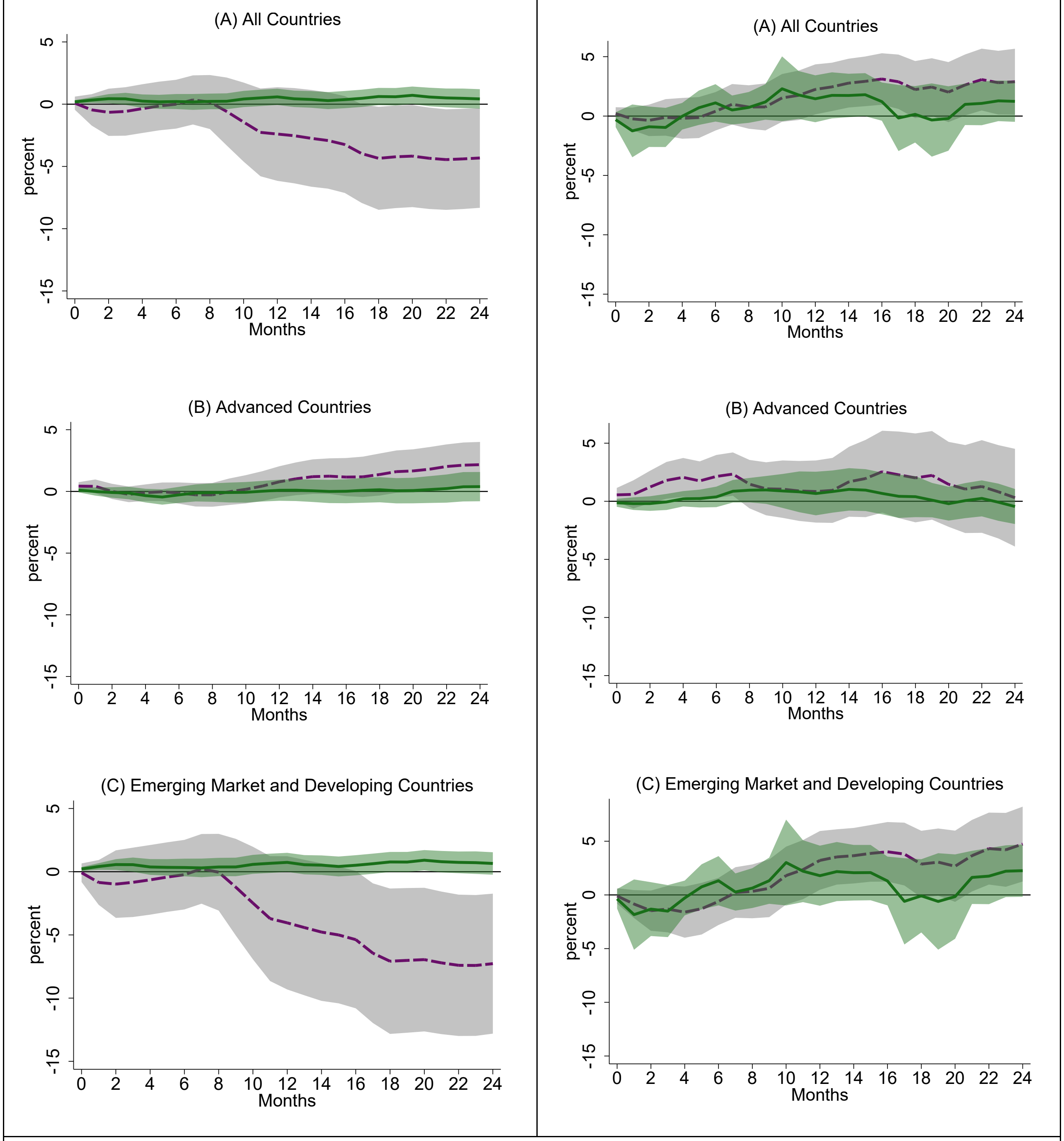


Note: The figure shows the cumulated response of NEER to natural disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of NEER implies an exchange rate appreciation (depreciation).

Source: Authors' calculations.

Figure 6: Cumulative Impulse Responses of REER to Disaster Shock by Disaster Type

Cimatic events | Geological events

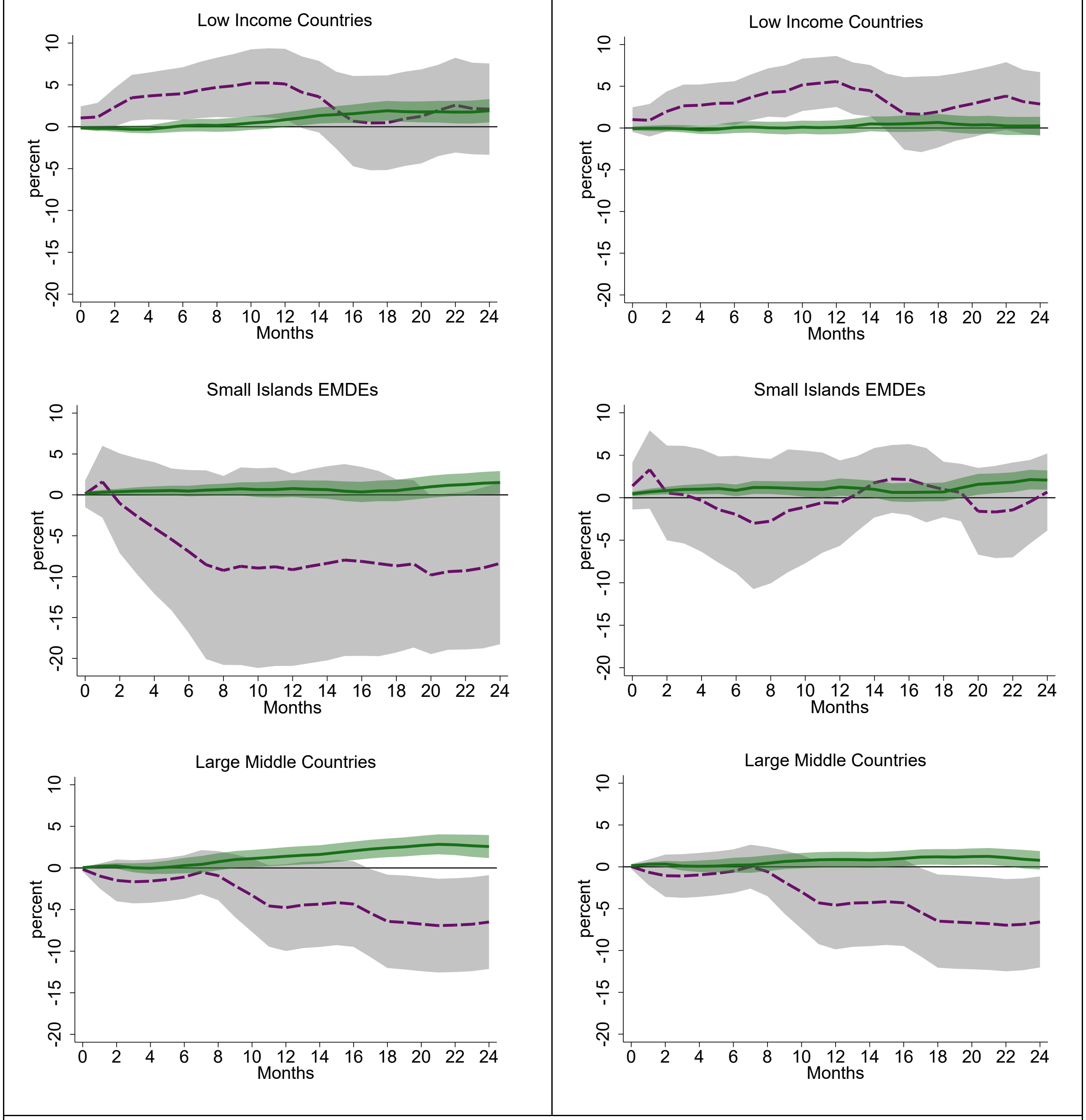


Note: The figure shows the cumulated response of REER to corresponding disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of REER implies an exchange rate appreciation (depreciation).

Source: Authors’ calculations.

Figure 7: Cumulative Impulse Responses of NEER and REER to Disaster Shock by Country Group

NEER REER

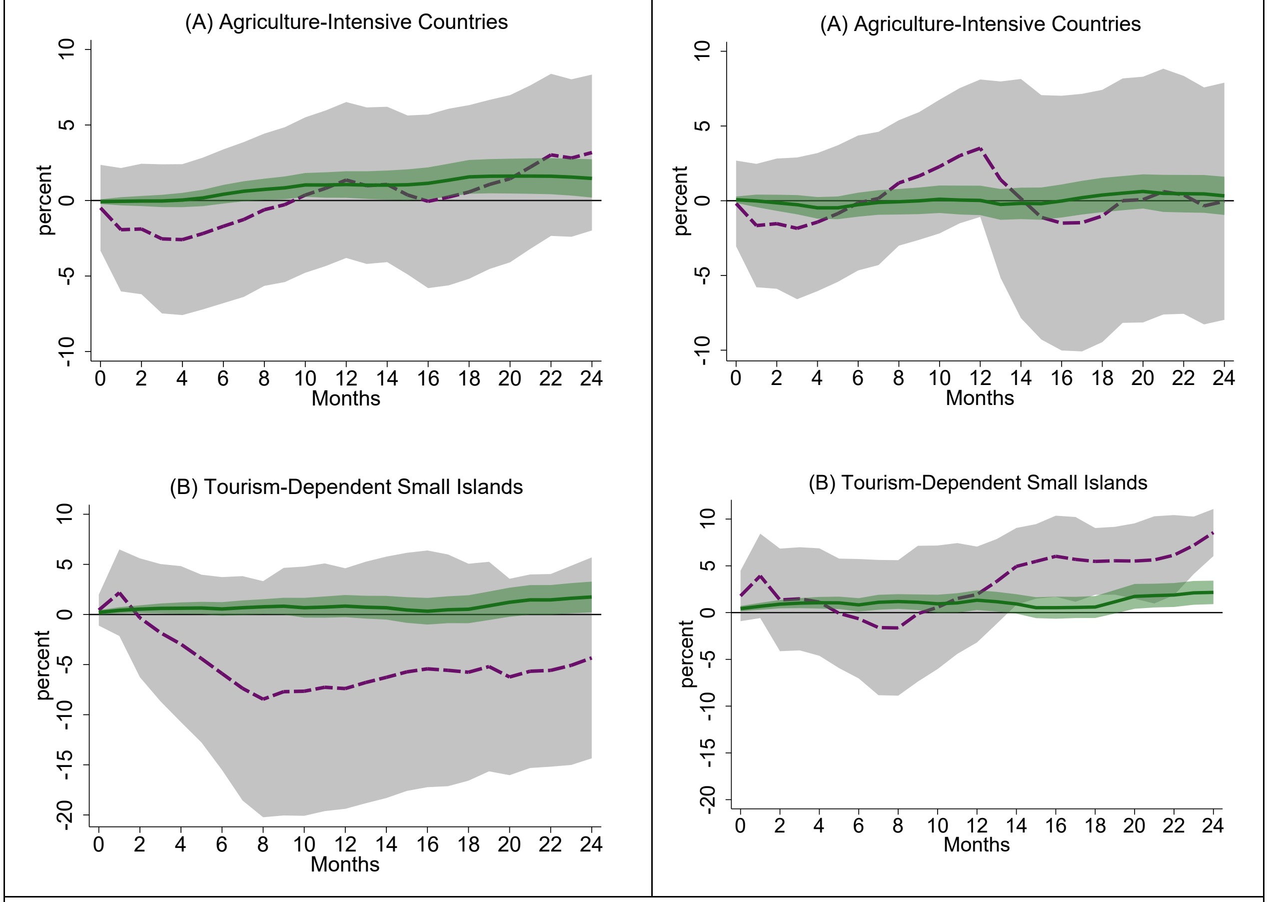


Note: The figure shows the cumulated response of the exchange rates to disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) in EER implies an exchange rate appreciation (depreciation).

Source: Authors' calculations.

Figure 8: Cumulative Impulse Responses of NEER and REER to Disaster Shock for Agriculture and Tourism Countries

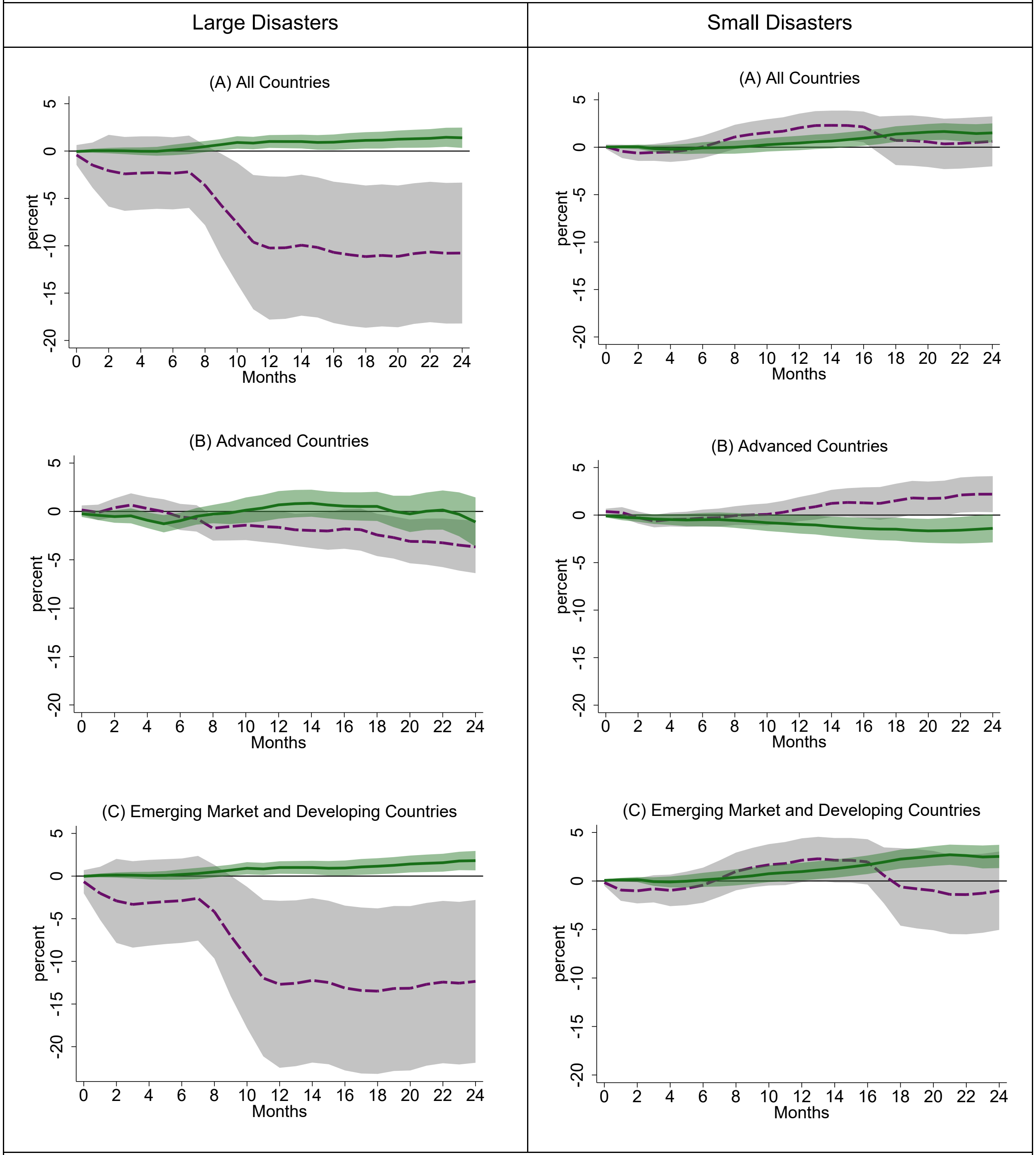
NEER	REER



Note: The figure shows the cumulated response of the exchange rates to disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) in EER implies an exchange rate appreciation (depreciation).

Source: Authors' calculations.

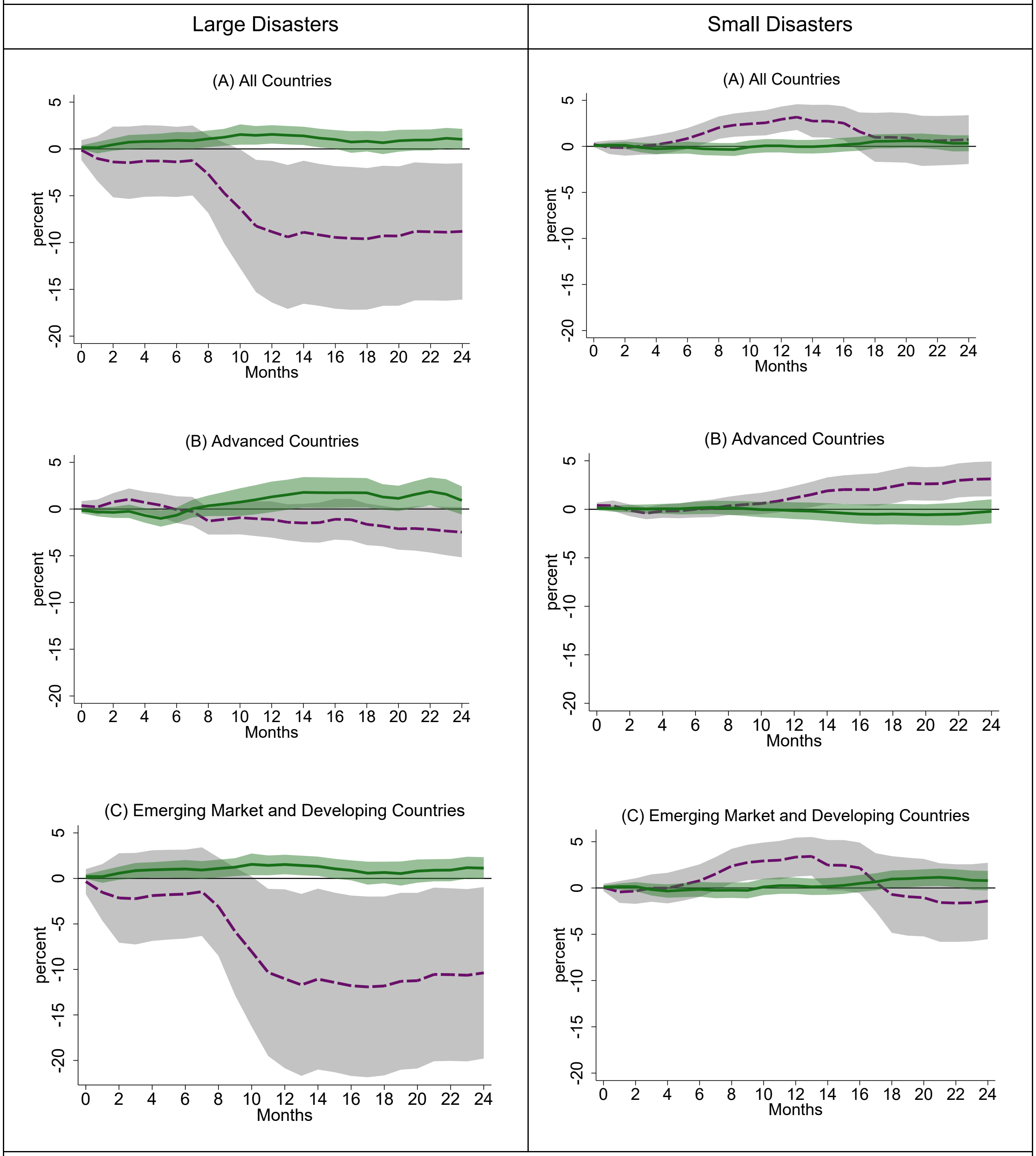
Figure 9: Cumulative Impulse Responses of NEER to Disaster Shock by Disaster Size



Note: The figure shows the cumulated response of NEER to disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of NEER implies an exchange rate appreciation (depreciation). Disasters with economic cost of top 25 percentiles are considered large disasters.

Source: Authors' calculations.

Figure 10: Cumulative Impulse Responses of REER to Disaster Shock by Disaster Size

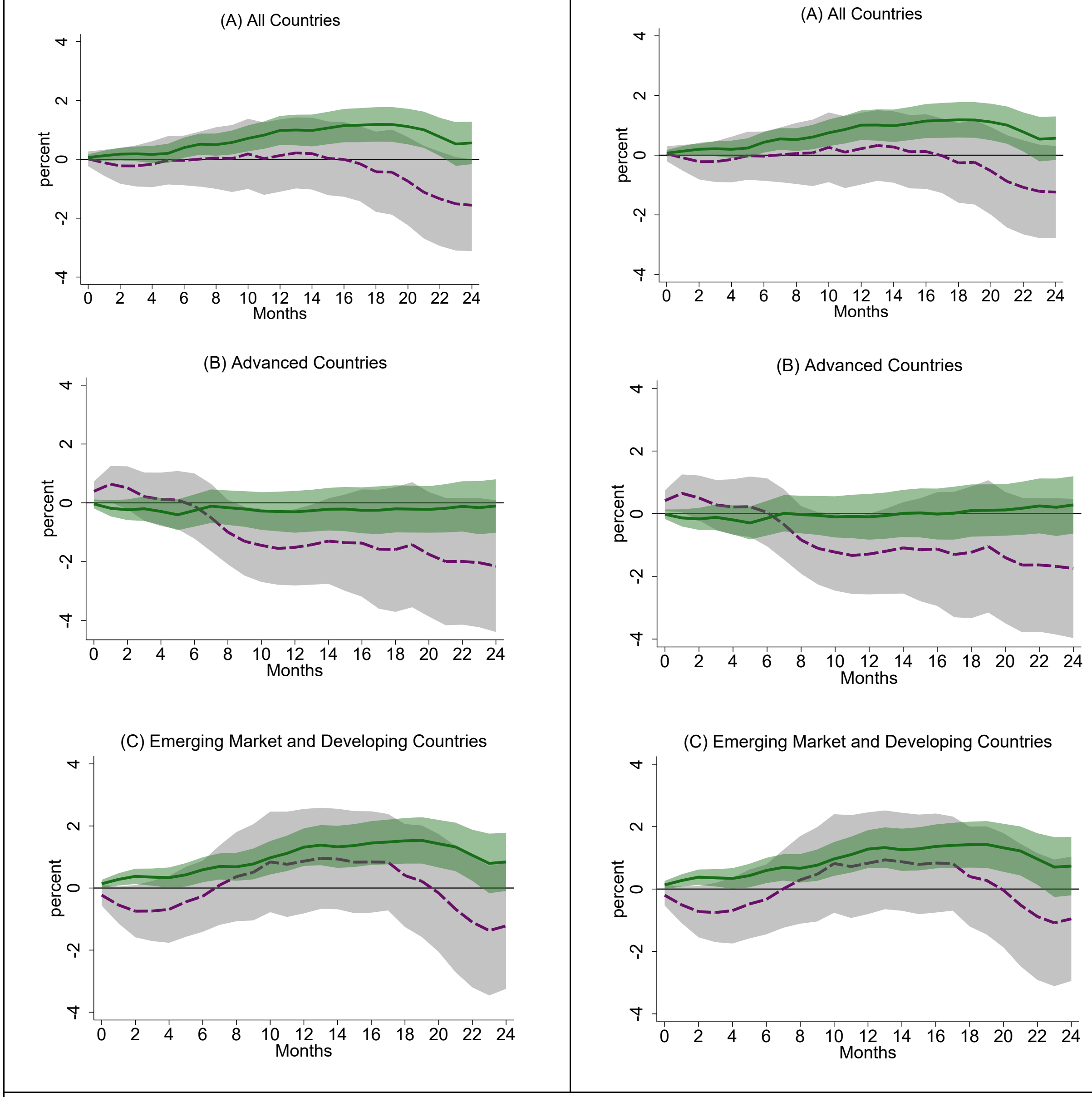


Note: The figure shows the cumulated response of REER to disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of REER implies an exchange rate appreciation (depreciation). Disasters with economic cost of top 25 percentiles are considered large disasters.

Source: Authors' calculations.

Figure 11: Robustness Check 1 – Cumulative Impulse Responses of REER to Disaster Shock with Two Additional Control Variables

Robustness Model (including lags of interest rate differential and change in capital account openness)	Baseline Regression with Restricted Sample (the same sample of the robustness model)



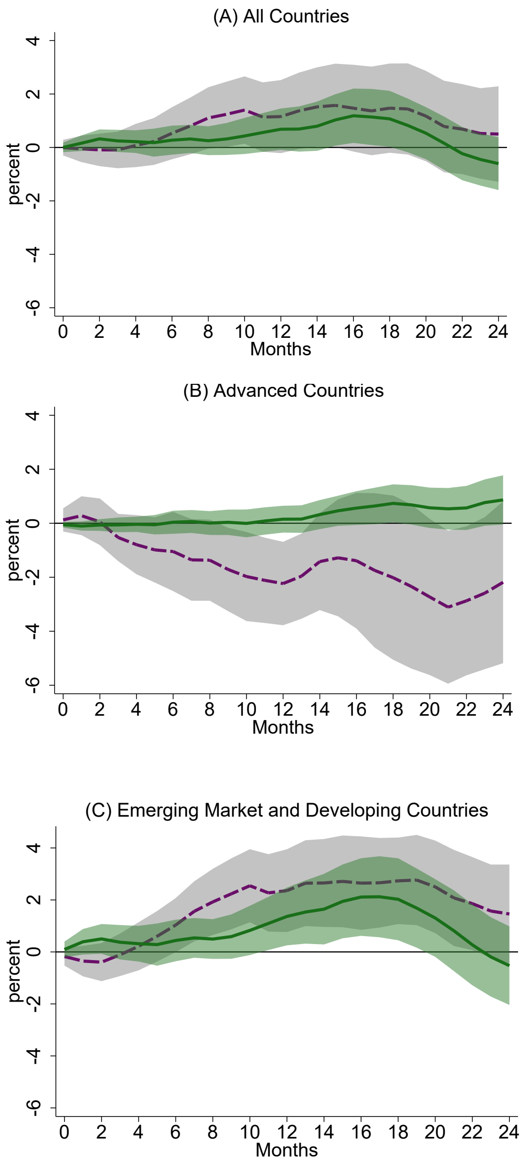
Note: The figure shows the cumulated response of REER to natural disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of REER implies an exchange rate appreciation (depreciation). The restricted sample excludes observations without interest rate data.

Source: Authors' calculations.

Figure 12: Robustness Check 2 – Cumulative Impulse Responses of REER to Disaster Shock with Three Additional Control Variables

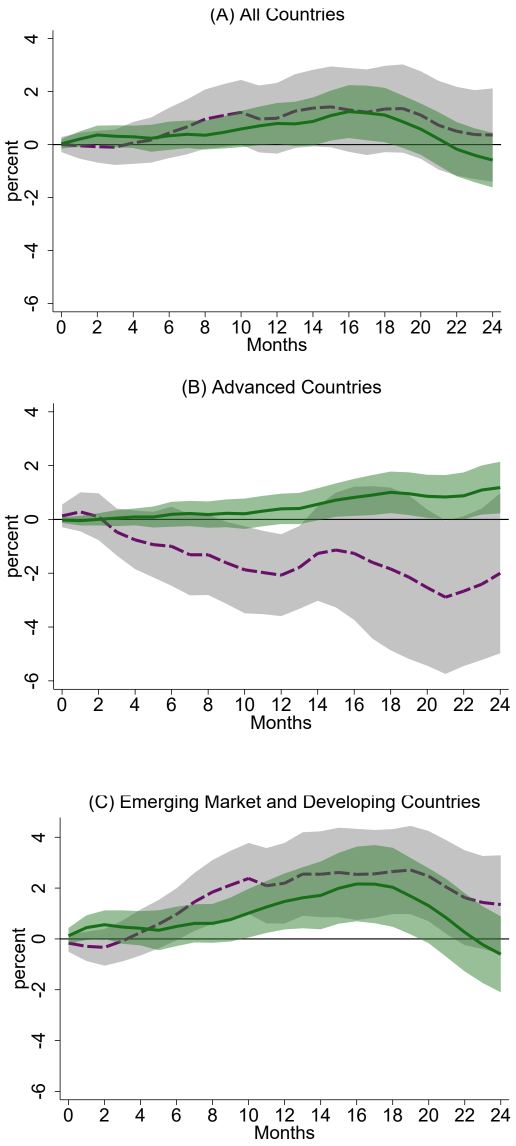
Robustness Model

(including lags of interest rate differential, change in capital account openness, and change in international reserves)



Baseline Regression with Restricted Sample

(the same sample of the robustness model)



Note: The figure shows the cumulated response of REER to natural disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of REER implies an exchange rate appreciation (depreciation). The restricted sample excludes observations without interest rate data and reserves data.

Source: Authors' calculations.

Appendix Table 1: Variables Descriptive Statistics

Variables	No. of observation	Mean	Standard Deviation	Min	Max	Sources
NEER	98,723	5.59	3.22	-14.35	37.97	Darvas (2021)
REER	86,121	4.67	0.44	-1.57	15.49	Darvas (2021)
CPI	76,938	3.47	2.14	-17.33	7.40	Ha et. al (2021)
Nominal interest differential	43,409	4.93	7.95	-17.00	59.91	Haver Analytics
Real interest differential	36,874	0.89	6.69	-99.03	50.68	Authors' calculations
Capital account openness	87,564	0.00	1.53	-1.93	2.30	Chinn and Ito (2006)
International reserves	15,742	10.00	1.75	5.37	15.19	IMF

Note: NEER, REER, CPI, and Reserves are in natural logarithm. Nominal interest differential is calculated as domestic policy rates minus policy rates of the base country. Real interest differential is calculated as real domestic policy rates (nominal rates minus annual inflation) minus real policy rates of the base country.

Appendix Table 2: Exchange Rate Regimes Definition

Code	Coarse Classification	Exchange Rate Regimes
1	No separate legal tender	Peg
1	Pre-announced peg or currency board arrangement	Peg
1	Pre-announced horizontal band that is narrower than or equal to +/-2%	Peg
1	De facto peg	Peg
2	Pre-announced crawling peg	Peg
2	Pre-announced crawling band that is narrower than or equal to +/-2%	Peg
2	De factor crawling peg	Peg
2	De facto crawling band that is narrower than or equal to +/-2%	Peg
3	Pre announced crawling band that is wider than or equal to +/-2%	Non-peg
3	De facto crawling band that is narrower than or equal to +/-5%	Non-peg
3	Moving band that is narrower than or equal to +/-2% (i.e., allows for both appreciation and depreciation over time)	Non-peg
3	Managed floating	Non-peg
4	Freely floating	Non-peg
5	Freely falling	*(dropped)*
6	Dual market in which parallel market data is missing	Non-peg

Source: Ilzetzki et. al (2019)

Appendix Table 3: List of Agriculture Intensive and Tourism Dependent Country	
Agriculture intensive country	Afghanistan, Bangladesh, Benin, Burkina Faso, Bhutan, Burundi, Cambodia, Central African Republic, Cote d'Ivoire, Chad, Cameroon, Comoros, Democratic Republic of Congo, El Salvador, Ethiopia, Micronesia, Ghana, Gambia, Guinea-Bissau, Haiti, India, Kenya, Kyrgyz Republic, Lao PDR, Liberia, Madagascar, Malawi, Mali, Mauritania, Myanmar, Mongolia, Mozambique, Niger, Nigeria, Nepal, Pakistan, Papua New Guinea, Rwanda, Sudan, Solomon Islands, Sierra Leone, Togo, Tajikistan, Tanzania, Uganda, Uzbekistan, Vietnam, Yemen Republic.
Tourism dependent small islands	Malta, Antigua and Barbuda, Bahamas, Barbados, Dominica, Grenada, Belize, Jamaica, St. Kitts and Nevis, St. Vincent and the Grenadines, Cyprus, Maldives, Cabo Verde, Mauritius, Sao Tome and Principe, Seychelles, Fiji, Samoa, Tonga

Source: World Development Indicator, United Nation World Tourism Organization, and authors' calculations.

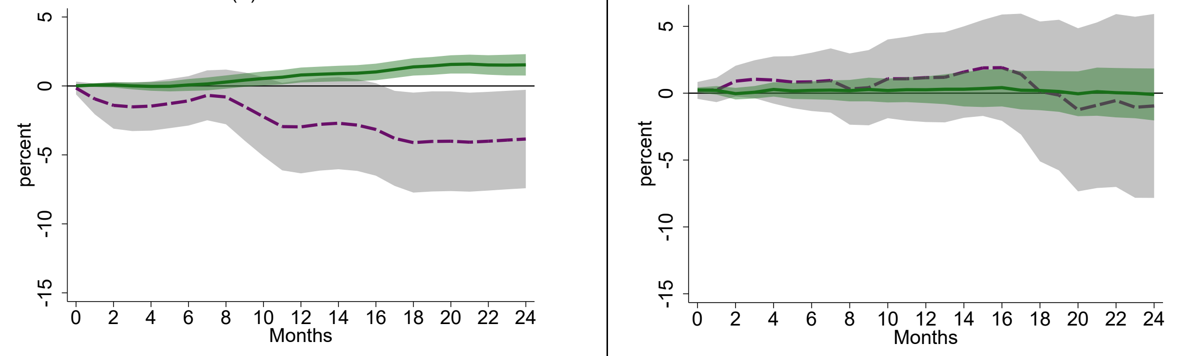
Appendix Figure 1: Plots of NEER data in Darvas dataset and IMF IFS dataset for selected EMDEs

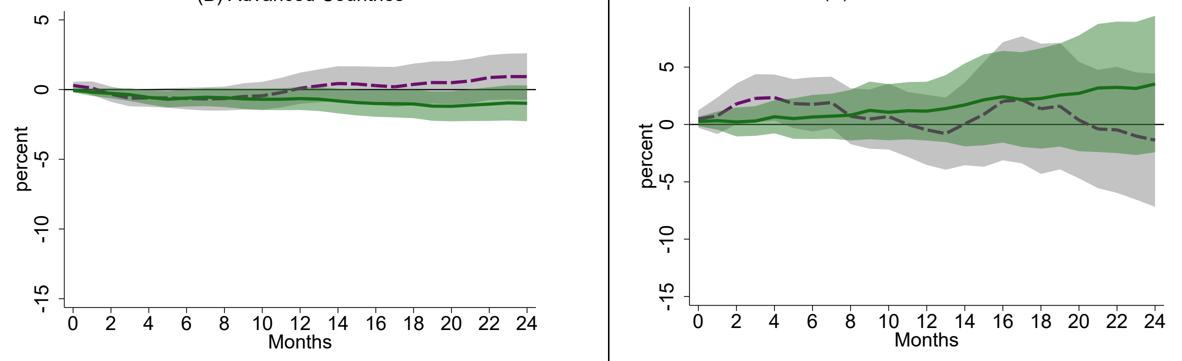
Notes: Solid green line (purple long-dash line) plots NEER in Darvas (IMF IFS) dataset in natural logarithm for randomly selected EMDEs in Asia, Africa, and Latin America.

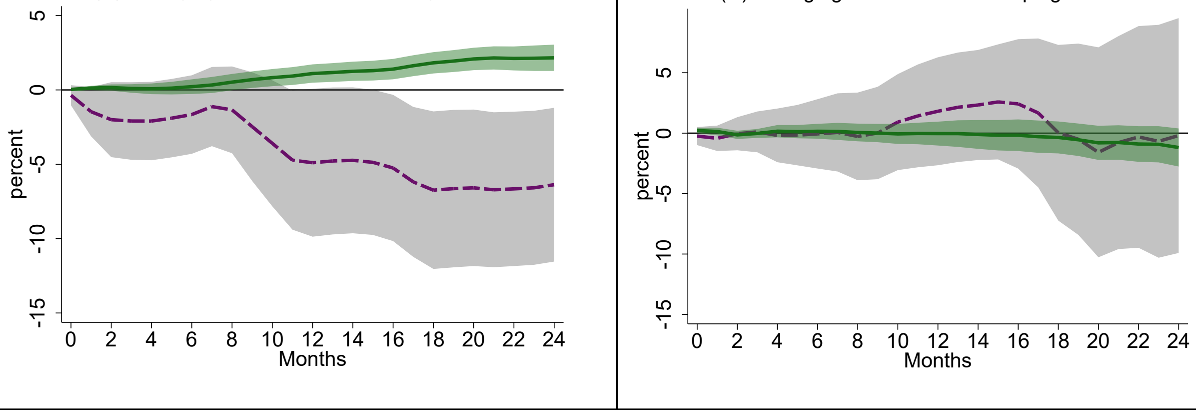
Souces:Darvas, IMF IFS, and author calculations.

Appendix Figure 2: Robustness Check - Cumulative Impulse Responses of NEER to Disaster Shock by Disaster Type (Alternative Classification)*, 1970-2019

Climatic events | Geological events


(A) All Countries | (A) All Countries


(B) Advanced Countries | (B) Advanced Countries

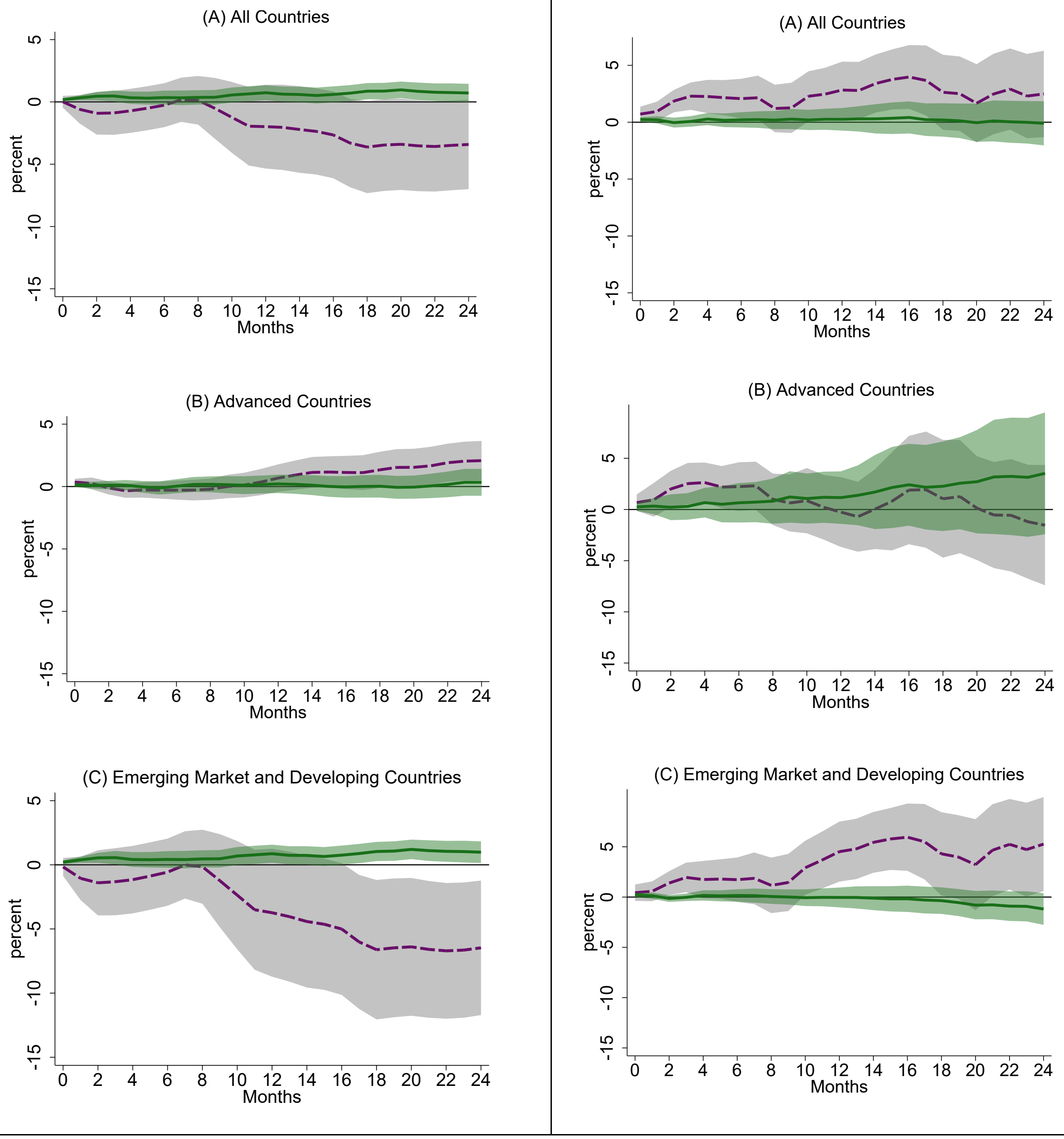

(C) Emerging Market and Developing Countries | (C) Emerging Market and Developing Countries

Note: *See footnote 5 for more details.

The figure shows the cumulated response of NEER to natural disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of NEER implies an exchange rate appreciation (depreciation).

Source: Authors' calculations.

Appendix Figure 3: Robustness Check - Cumulative Impulse Responses of REER to Disaster Shock by Disaster Type (Alternative Classification)*, 1970-2019



Climatic events

Geological events

Note: *See footnote 5 for more details.

The figure shows the cumulated response of REER to natural disaster shocks in countries with fixed (green line) and flexible (dash purple line) exchange rate regimes. The green (purple) shaded area shows confident intervals at 90 percent level for fixed (flexible) regimes. An increase (decrease) of REER implies an exchange rate appreciation (depreciation).

Source: Authors' calculations.

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