Resour Environ Econ, 2020, 2(2): 172-183
DOI: 10.25082/REE.2020.02.003

RESEARCH ARTICLE

Impact of natural disaster shocks and macroeconomic growth in Asia

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Abstract: Climate-related natural disaster shocks are expected to rise as the earth is getting warmer, which will adversely affect growth globally. Empirically, the effects of typhoons and droughts have negative impacts on economic growth and would likely to persist up to 2 decades. Using the typhoon landfalls and damage in Asia, we analyze the winddamage relationship and find damages to gross domestic product increase by 2.3% for an increase in maximum wind speed. The extreme projected temperature rise in Representative Concentration Pathway (RCP) 8.5 will result in higher typhoon damage by more than 50% in 2100. Vulnerable developing Asian economies could expect dampened growth with significant impacts on agriculture and tourism, a concern that may undermine years of development and worsen inequality. To cope with increasing disaster risks, both short-term adaptation strategies like relocation, government transfers, and other social safety nets, as well as long-term strategies are needed.

Keywords: natural disaster, typhoons and droughts, Representative Concentration Pathway, macroeconomic growth, Asia

1 Introduction

Risks associated with extreme weather events or shocks (heat waves, heavy rainfall, and coastal flooding) will continue to increase as the global mean temperature rises[1]. Climate change, warmer sea temperatures in particular, will result in extreme weather patterns and more frequent high-intensity storms in selected ocean basins[2,3].

Climate-related natural disasters are expected to rise as the earth is getting warmer with the prospect of significant negative impacts on economic growth. Analyzing 750 empirical estimates, Klomp and Valckx[4] show negative effects on economic growth per capita with developing countries severely affected by climatic shocks. Felbermayr and Gröschl[5] find that natural disasters reduce per capita gross domestic product (GDP) by up to 6.8% on impact or in the year they occur. A separate study also reports that both typhoons and floods negatively affect not only per capita GDP but also the debt ratio[6]. (Also called hurricane in the Atlantic and cyclone in the Indian and South Pacific Ocean. These terms are used interchangeably in this paper.) Vulnerable economies like the Pacific islands could expect growth to drop by 0.7 percentage points due to damage equivalent to 1% of GDP in the year of the disaster[7].

Herring *et al.*[8] shows that anthropogenic activity (greenhouse gas emissions and land use) influenced specific weather climate. The destruction caused by Typhoon Haiyan in 2013 in the Philippines, one of the strongest recorded typhoons to make landfall, resulted in total economic loss of around USD10 billion, left 6,300 people dead and damaged over 1 million houses[9]. Climate disasters have thus become a concern with the likelihood of rolling back years of development gains and exacerbate inequality[10,11].

Plotting the occurrence of all natural disasters (climate related and geophysical) from the Emergency Events Database (EM-DAT[12]) have been increasing particularly storms and floods. Storms, earthquakes and floods generated the most damage to social and physical infrastructure. This includes catastrophic events like Hurricane Katrina in 2005, the Great East Japan earthquake in 2011, and Typhoon Haiyan in 2013. Aside from lives lost, estimated total damages from climate-related disasters are staggering. From 1960 to 2015, storms caused at least USD1.04 trillion in damages, earthquakes caused USD771 billion and floods at USD696 billion in damages.

Developing countries, especially the low- and middle-income economies, are most at risk and where most vulnerable populations are located. Data from EM-DAT[12]

Received: February 13, 2020 **Accepted:** July 3, 2020 **Published:** July 17, 2020

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Citation: Lee M, Alano E and Villaruel ML. Impact of natural disaster shocks and macroeconomic growth in Asia. *Resour Environ Econ*, 2020, **2**(2): 172-183.

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show that since 1960, 99% of the affected population (87% middle income, 12% low income) and 967% of deaths caused by disasters (64% middle income, 32% low income) are in developing economies. Weighted by land area and population, small island states are exposed to more frequent natural disasters[13]. In terms of total damages caused by climate-related disasters, advanced economies were the hardest hit, mainly due to the higher cost of physical capital and infrastructure, followed by developing Asia. Within the region, East Asia has the largest damages in United States (US) dollar terms Table 1(Includes Japan; the Republic of Korea; Hong Kong, China; Taipei,China; and the PRC.).

Table 1 Estimated Total Damages due to Climate-Related Disasters by Region, 19602015(USD billion)

Region	Total Damages
Advanced economies (OECD)	1,160
Developing Asia	610
East Asia	374
South Asia	122
Southeast Asia	108
Central Asia	3
The Pacific	2
Latin America and the Caribbean	141
Rest of the world	57
Middle East and North Africa	26
Sub-Saharan Africa	14

Note: OECD = Organisation for Economic Co-operation and Development. Source: Authors calculation based on EM-DAT: The OFDA/CRED International Disaster Database. Brussels, Belgium: Catholic University of Louvain. http://www.emdat.be/

Due to their geographical location and archipelagic features, most of the low-income countries and small states, particularly in Sub-Saharan Africa and Pacific island states, are vulnerable to natural disasters. From 1985 to 2015, these countries were hit almost twice as often by climate-related disasters like floods, storms, and droughts[14]. Among the Asian countries included in the World Risk Report (Created by the United Nations University Institute for Environment and Human Security (UNU-EHS)[15] in 2011 and indicates the risk of disaster due to extreme natural events for 171 countries. Available at http://www.worldriskreport.org/) since 2011 as having the highest disaster risks are Pacific island states like Vanuatu, Tonga, Solomon Islands, Timor-Leste, and Papua New Guinea as well as archipelagic countries like the Philippines. The proportion of the domestic population affected by natural disasters is also higher compared with high-income countries, particularly for small developing and low-lying coastal states. Within these countries, the poorest 25th percentile of countries, mostly in Sub-Saharan Africa, faces the highest natural disaster risks[14].

This study will document the effects of natural disasters to vulnerable economies and identify adaptation strategies and mitigation options to reduce the impact to the economy. The paper is organized as follows: Section II provides quantitative effects of typhoon and droughts to the economy and tourism and empirical analysis on the impact of typhoon intensity to GDP. This section will also present the Philippine case study. Section III discusses the adaptation and mitigation measures followed by policy recommendations in Section IV. Section V concludes.

2 Effect of Natural Disasters

Climate-related natural disasters and temperature rise can harm growth and exacerbate poverty in developing countries. Natural disasters may reduce developing countrys growth by an estimated 13 percentage points, depending on the type of disaster. (See Farid *et al.*[14] for macroeconomic impacts specifically, Raddatz[16]and Loayza *et al.*[17] on climatic disasters, Fomby, Ikeda, and Loayza[18] on severe droughts, Acevedo[6] on impacts for the Caribbean, and Cabezon *et al.*[7] on the Pacific Islands.) Climate change and natural disaster risks worsen poverty due to loss of productive economic assets combined with limited savings[19] and food vulnerability. Countries with weak institutions and unstable domestic food production as measured by food supply per capita growth tend to experience frequent food crises, while countries with sound macroeconomic fundamentals such as low fiscal deficit and higher food reserves experience a lower likelihood of a food crisis[20].

2.1 Macroeconomic Effects

Temperature rise is also linked to lower growth, for example, Dell, Jones, and Olken[21] find that in poor countries a 1C rise in temperature from a countrys annual mean temperature reduces economic growth by 1.3 percentage points on average, mainly by reducing agricultural output. Increasing temperature and rainfall volatility together with extreme weather events reduce agricultural productivity in low-income countries, an important growth channel given agricultures large share in output in these countries[14]. However, Lee, Villaruel, and Gaspar[22] confirms that aside from agricultural production, industrial production and investment are potential channels through which temperature significantly affects the overall economic productivity.

Hsiang and Jina[23] assert that growth effects brought on by tropical cyclone strikes linger for almost 2 decades, with economies not recovering in the long run. Using 60 years of cyclone (in terms of wind speed) and economic data to estimate the long-term effects of climatic disasters on output, they find that national incomes substantially decline compared to predisaster trends and economic recovery does not happen for 20 years both for poor and rich

Table 2 Global Estimates of Macroeconomic Impacts of Natural Disaster Shocks

Study	Natural Disaster	Effect on Income (GDP per capita growth) (%)	Observed After
Hsiang and Jina (2014)	1 standard deviation tropical cyclone	–3.6	20 years
	90th percentile cyclone	–7.4	20 years
	99th percentile cyclone	–14.9	20 years
Felbermayr and Gröschl (2014)	average cyclone	–0.16	on impact
	95th percentile cyclone	–1.75	on impact
	95th percentile drought	–0.34	on impact
Loayza et al. (2012)	Droughts	–0.6	1 year
		–3.0	5 years
Mendelsohn et al. (2012)	Tropical cyclones	USD26 billion or 0.04% of current global GDP USD56 billion by 2100	annual
Fomby, Ikeda, and Loayza (2009)	Droughts	–1.7	year of the event
	Storms	–0.3	year of impact

Note: GDP = gross domestic product. Source: Authors compilation.

countries Reductions in per capita GDP range from 3.6% to 14.9% lasting for 2 decades. Devastating cyclones like Hurricane Katrina or Typhoon Haiyan can have longer-lasting effects than a financial crisis. Projected estimates of monetary damages from cyclones up to 2100 range from 6% of GDP or USD860 billion for the case of the US to 83% of GDP or USD300 billion for the Philippines.

Various studies have tackled the disasterdevelopment nexus and generated estimates of global effects on GDP levels and per capita growth. Whereas the majority of these studies used EM-DAT data in growth regressions, generating some conflicting positive and negative results, more recent panel studies used a combination of EM-DAT data and exogenous variables such as wind speed and pressure for tropical cyclones and precipitation indices for droughts, uncorrelated with income measures such as GDP, to estimate output effects. This recent research also reported more robust results (see Table 2). (Except for Loayza *et al.*[17] who used EM-DAT data for the analysis.) While Hsiang and Jina[23] estimated long-run effects up to 2 decades and projections until 2090, others only provided short-run effects either on the year of impact or after 5 years, further evidence that damage from disaster shocks are not limited to immediate or direct effects.

Using a comprehensive database of disaster events and their physical intensities, Felbermayr and Gröschl[5] find robust and substantial negative effects of natural disasters on economic growth similar to estimates generated by Fomby, Ikeda, and Loayza[18]; however, there was no evidence of a subsequent temporary boom. Their results show that an average storm reduces output growth by 0.16% and a 5% strongest storm by 1.75%. Mendelsohn *et al.*[3] further estimates that tropical cyclones reduce current global output by USD26 billion or 0.04% every year which is projected to double to almost USD56 billion by the end of this century.

By performing counterfactuals using their estimates to see what would happen if there were no cyclones from 1950 to 2008, Hsiang and Jina[23] found that world GDP growth would have been 1.4% higher per year. In selected developing Asian economies, typhoons have resulted in significant“lost growth” for the period from 1970 to 2010 of as high as 7.3% of GDP per capita in the Philippines (Table 3). Together with macroeconomic effects of temperature variation by 2100, the estimated damage from tropical cyclones, which can exacerbate poverty and undermine social welfare[13], can dampen growth and put considerable economic pressure especially on vulnerable populations in developing Asian economies.

The distribution of intense cyclone events is expected to shift toward fewer low-intensity cyclones but more frequent high-intensity events. Modeling studies project substantial increases in the frequency of the most intense cyclones, with an increase of about 20% in the precipitation rate within 100 kilometers of the storm center[24]. The average typhoon intensity is also projected to increase by an additional 14% by 2100[2].

Moreover, the “damage functions” or the elasticity of damage to GDP by typhoon intensity measured by wind speed has also been extensively studied and estimated for use in climate change research, particularly in integrated assessment models. Using data on hurricanes in the US, various studies estimated elasticity at 3.8[25], 5[3], between 6 and 8[26], and 9[27]. In the Caribbean, Acevedo[28] estimated it at 2 for nonlandfall and 3.2 for landfall cyclones.

The best-track data for selected Asian economies were taken from the International Best Track Archive for Climate Stewardship[29] with information on maximum wind

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Table 3 Macroeconomic Impacts in Selected Developing Asian Countries: Temperature Variation vis--vis Tropical Cyclone Shocks

Countries	Temperature Effects on GDP Per Capita Growth by 2100(%)		Estimated Loss Using 5% Discount Rate by 2090		Cyclone Climate Growth Penalty ("Lost" Growth), 1970–2010
	RCP8.5	RCP2.6	USD billion, 2010 PPP	% of GDP, 2010 PPP*	GDP per capita growth, %
Philippines	–4.2	–1.0	–299.3	81.5	–7.28
Viet Nam	–4.9	–1.2	–160.1	57.9	…
Thailand	–5.6	–1.3	–140.6	24	–2.17
Indonesia	–4.4	–0.9	–10.9	1.1	–1.57
Malaysia	–4.8	–1.1	–9.8	2.4	–0.25
Cambodia	–5.7	–1.4	–9.3	30.6	…
Lao PDR	–4.7	–1.1	–9.2	58.4	…
Developing Asia	–2.5	–0.5	…	…	…

Note: … = data not available, GDP = gross domestic product, Lao PDR = Lao People′s Democratic Republic, PPP = purchasing power parity, RCP = Representative Concentration Pathway. * GDP 2010 PPP from World Development Indicators. Sources: Authors′ compilation from Hsiang, Solomon and Amir Jina[23] and Lee, Minsoo, Mai Lin Villaruel, and Raymond Gaspar[22].

speed and minimum pressure for the duration of the typhoon.(Based on Knapp *et al*.[30]. Includes economies in developing Asia (Cambodia; India; Lao Peoples Democratic Republic; Myanmar; Philippines; PRC; Solomon Islands; Taipei,China; and Vanuatu) and Japan.) Typhoons which made landfall were identified by overlaying the IBTrACS data within a global grid. Data on damages were taken from the EM-DAT database(Estimated damages in US dollars, which is the total of insured and noninsured losses from various sources. This include amount of damages to property, crops, and livestock.) and GDP-level data from the World Bank's World Development Indicators[31].

This paper uses a modified winddamage function, a log-log model estimated using panel fixed effects, adopted from Nordhaus[27] and Acevedo[28] (Alternatively, using a log-linear model, these papers find that the semi-elasticity of maximum wind speed to damages is 0.0535. Hsiang and Narita[32] estimate a semi-elasticity of 0.010 showing th1at a 1.9 knot per hour (1 meter/second) increase results in 10% increase in damages.) :

$$ln\left(\frac{Damages_{ijt}}{GDP_{ijt}}\right) = \alpha + \beta \ln\left(Wind_{ijt}\right) + \sigma Year_t + \mu_j + \varepsilon_{ijt} \tag{1}$$

where Damages/GDP for each typhoon *i* in country *j* at year *t* is regressed on the maximum Wind speed achieved by each typhoon in the sample and a time trend Year. μ_j captures time-invariant country fixed effects and ε_{ijt} is the error term. The sample includes data on typhoons that made landfall from 1977 to 2014 for 10 economies with 113 observations.

Table 4 indicate that a 1% increase in typhoon intensity (wind speed in meters per second) results in an approximately 2.3% increase in the damages-to-GDP ratio. Intuitively, it also shows that both category 1 and 2 hurricanes exhibit increasing damage as the wind speed thresholds intensify. (Saffir-Simpson scale used for easy reference. See NOAA[33] website at http://www.nhc.noaa.gov/aboutsshws.php) Estimates from this paper show that in Asia, the elasticity is about 2.3. This approximates results from empirical studies that indicate damage as a function of the square or cube of wind speed.

With global warming, scientists believe that typhoons may further intensify. Emanuel[34] finds that with warmer sea surface temperatures comes the possibility of stronger storms. This increase in intensity further increases the damages and costs to countries in developing Asia regularly hit by this type of disaster shocks.

To approximate the increase in damages from typhoons due to global warming by 2100, the following parameters were used (Modified equation adopted from Acevedo[28] and Nordhaus[27]):

$$\Delta\left(\frac{Damages_t}{GDP_t}\right) = \left[\left(1 + \gamma\theta_t\left(T_t\right)^{\beta} - 1\right) \times 100\right] \tag{2}$$

where γ is the semi-elasticity of maximum wind speed relative to changes in the sea surface temperature,θ is the elasticity of sea surface temperature to a change in global temperature (T), and β is the winddamage elasticity estimated above (2.3). This study uses the same γ that Nordhaus[27] and Acevedo[28] use, γ = 3.5%, and θ assumes a 1:1 change in sea surface temperature with a change in T since the Representative Concentration Pathways (RCPs) do not project decadal changes in sea surface temperature.

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Table 4 Estimates of the Wind IntensityDamage Function

Variables	(1) Pooled (D)	(2) Pooled (D/GDP)	(3) Damage	(4) Damage/GDP	(5) Category 1 (D/GDP)	(6) Category 2 (D/GDP)
Maximum wind speed	1.7378*	2.3940**	2.4561***	2.3487**	2.4656**	6.9843*
Year	0.0777***	–0.0593***	0.0810**	–0.0260	–0.0367	–0.0142
Constant	–1.5e+02***	98.6914***	–1.5e+02**	32.2594	52.8588	–14.7882
R2	0.2112	0.1262	0.1981	0.0707	0.0809	0.3629
Observations	113	109	109	109	81	20
Countries	10	10	10	10	10	10
Fixed effects	No	No	Yes	Yes	Yes	Yes

Note: Cat 1= Category 1 hurricane with windspeed of 119-153 kilometers per hour, Cat 2 = Category 2 hurricane with windspeed of 154-177 kilometers per hour, D = damage, GDP = gross domestic product. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Source: Authors′ calculations.

Table 5 Estimated Increase in Mean Damages under Climate Change Scenarios

	Parameter estimates			Increase in Mean Damages (%)		
	β	γ	θ	SST (℃)	2050	2100
Nordhaus (2010)	9	0.035		2.5		112.7
Acevedo (2016)[a]	3.2	0.035		2.5		30.5
This study	2.3	0.035		2.5		21.3
Using RCP2.6 temperature projections						
Mean (T=1.1°C)	2.3	0.035	1	1.1	3.7	9.1
Low (T=0.6°C)	2.3	0.035	1	0.6	2	4.9
High (T=1.6°C)	2.3	0.035	1	1.6	5.4	13.4
Mean (T=1.1°C) and higher γ	2.3	0.05	1	1.1	5.3	13.1
Mean (T=1.1°C) and lower θ	2.3	0.035	0.6	0.7	2.2	5.4
Using RCP8.5 temperature projections						
Mean (T=4.3°C)	2.3	0.035	1	4.3	14.8	38.1
Low (T=2.7°C)	2.3	0.035	1	3	9.2	23.1
High (T=5.8°C)	2.3	0.035	1	5.6	20.3	53
Mean (T=4.3°C) and higher γ	2.3	0.05	1	4.3	21.5	56.5
Mean (T=4.3°C) and lower θ	2.3	0.035	0.6	2.6	8.8	22.2

Note: RCP = Representative Concentration Pathway, SST = sea surface temperature. [a] Only hurricanes that made landfall in the Caribbean. The RCP 2.6 and RCP 8.5 temperature projections are adopted from Lee, Minsoo, Mai Lin Villaruel, and Raymond Gaspar[22]. The former depicts meeting the COP21 target and the latter depicts the extreme projected temperature rise should the world fail to meet the target. Sources: Authors calculations based on Nordhaus, William[27] and Acevedo[28].

Table 5 shows that mean damages in Asia will increase by 21% by 2100 using the same sea surface temperature as Nordhaus (2.5C). Using projected temperature changes (low, mean, and high) under the RCP2.6 scenario, mean damages increase in the range from 5% to 13%. Higher damages as high as 53% result under extreme temperature changes in the RCP8.5 scenario. By performing a sensitivity analysis using a higher and lower , the range of damages is essentially the same as the results from the RCP scenarios, from 5% to 56%(Higher γ is from Emanuel[34] who finds a 5% increase in maximum wind speed with a 1% increase in sea surface temperature.).

Compared to tropical cyclones which are“rapid onse” events, droughts are“slow onse” events that affect a wide area and can have significant economic impacts over long periods. Felbermayr and Gröschl[5]find that an average drought reduces output by 0.01% while a top 5% strongest drought reduces it by 0.34%. Loayza *et al.*[17]ocument that in developing countries, a typical drought reduces the agricultural and industrial annual growth rate by 1 percentage point, leading to a decline of GDP growth by 0.6 percentage point per year (or 3% over a period of 5 years). A separate study by Fomby, Ikeda, and Loayza[18] found that droughts have a negative overall effect on GDP per capita growth, especially in the year of the event. The cumulative effect is 1.7% of GDP growth and 1.6% for agricultural growth. It also has a negative impact on nonagricultural growth, though delayed, up to the third year. Using a global dataset and historical data of precipitation variability, Brown *et al.*[35]found that a

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1% increase in a country's area experiencing drought results in a 2.8% reduction in annual GDP growth. The prolonged drought in Southeast Asia in 2016 severely affected the Mekong region, which produces 100 million tons of rice annually or 15% of the world's total, resulting in Vietnam's lowest rice output since 2005[36].

Exposure to climate change and related extreme weather events affects tourism, a sector dependent on the weather and geographical location. It is expected to affect tourists destination choices, creating different patterns of tourism flows at the regional level. Losses are expected for most developing countries while high-latitude advanced economies would gain[14,37]. In 28 Caribbean countries, the impact of cyclones on tourism-related income is disproportionately large[38]. Data on total income attributed to tourists from 1995 to 2006, across all industries, reveal substantial losses that persist up to 4 years relative to a trend and relative to the previous year. The effect is large, estimated as high as 3.5% of tourism receipts and 2.8% of visitor the following year. These are due to reductions in aggregate tourist visits, rather than by reductions of income per visit. Tourism-related industries are hit hard as well as cyclones negatively affect the wholesale, retail, restaurants, and hotels sector, with output at -0.9% in the year of impact, and persist in the second and third years at -0.3%. This contrasts with positive effects on the construction industry at 1.4% from the year of the impact until the following year, due to demand brought by reconstruction and rebuilding efforts.

Drought effects are vast economically and socially and in fact, becoming increasingly complex, but less attention on its impact to tourism[39]. In a study conducted by University of Arizona[40], drought will decrease the levels of lakes, rivers and snow falls in the mountains which provide outdoor tourism and recreation activities, including water sports, skiing, hiking, and camping. Further, the study also point out that drought will decrease visitor arrivals thus affecting jobs in the sector. For example, the 5.4 percent drop in water level at Lake Powell from 1999 to 2003 contributed to half a million fewer visits to the Glen Canyon National Recreation Area in 2003. The marked decreaseis in visitors resulted in USD32.1 million loss in spending in the area, along with 758 jobs and USD13.4 million in personal income.

2.2 Case Study: Philippines

The Philippines is one of the developing Asian countries regularly hit by typhoons. Weather-related disasters account for 90% of annual economic damage from all natural disasters in the Philippines, making it one of the countries most exposed to climate change risks. (Economic damages refer to the monetary value of the negative impact of weather-related disasters on the affected economic and social sectors. Estimates calculated from raw data in IBTrACS[29].) Annually, an average of 19 typhoons enter the country, of which 9 or 10 typhoons make landfall[41,42]. While there were fewer typhoons (above 115 kilometers per hour), stronger typhoons (above 150 kilometers per hour) affected the country from 1951 to 2013[42]. Since 1990, these typhoons have been getting stronger with the highest maximum wind speed recorded in November 2013 during Typhoon Haiyan.

Typhoon Haiyan, a category 5 cyclone locally known as Yolanda, was the strongest typhoon to ever make landfall in the country. For a country used to being battered by typhoons every year, the devastation was staggering. Total damages are estimated at P(Peso) 101.79 billion or 0.9% of gross domestic product[43]. The affected regions account for about 13% of GDP. When two typhoons hit the bigger Luzon regions in 2009, fourth quarter growth rate was a low 1.4%[44]. The poor are also the hardest hit as the t.yphoon affected eight provinces with high levels of poverty incidence. If about 10% of the estimated 4 million people displaced and 5% of the 12 million directly affected by the typhoon become newly poor, there would be an additional 1 million poor people in the country, increasing poverty incidence by 4%[44].

The average Filipino household suffers the impacts of typhoons, with a significant decrease in income and expenditures on basic items, as well as increased infant mortality a year after typhoon exposure . One potential long-term effect is also the low birth weights which may affect later life outcomes like low education level, lower earnings, and adverse health outcomes[45].

Generally, the Philippines has weathered the storms with surprising resiliency through sufficient fiscal space, strong financial markets, and stable remittances[44]. In 2013, the economy grew by 7.2%, one of the highest in Asia. This growth was underpinned by strong macroeconomic fundamentals such as growth in remittances and in the service sector, and high domestic demand that has shielded the Philippines from persistent disasters[46]. However, the country has been unprepared for major disasters in recent years.

3 Adaptation and mitigation to Natural Disaster Shocks

It is feasible and cost-effective for vulnerable countries to invest heavily in adaptation, as adaptation initiatives can prevent about 3% of GDP loss due to cyclones[32]. Country-level measures to lessen disaster risks include relocation or migration, climate-resilient infrastructure and improved building and fire codes, preventive mea-

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sures such as early warning systems and faster emergency response systems, other safety nets like government transfers and risk-sharing mechanisms such as development aid and disaster insurance. Adaptive capacity increases with income[47]. Rich countries are better equipped because of better public services such as wide access to insurance, financing, and stronger institutions that provide safety nets and more resources for enforcing building and safety codes. This is a form of "adaptation defici" which poorer countries lack and limits their ability to adapt[48]. Government-funded transfer programs such as unemployment insurance, welfare, and food stamps are some of the safety nets available to affected populations, which explains the relative resilience of the US to natural disasters[49]. Richer countries simply have more resources to protect against natural disasters[48].

3.1 Migration and Urbanization

Agriculture and tourism, two production sectors dependent on weather and geographical location, are the most affected by typhoons. These are also the sectors that adapt the least to disaster risk. This suggests that nonagricultural and other industries can adapt more quickly through less costly strategies such as relocation[38]. Diversification into manufacturing is also an economic strategy especially for sectors relying on agriculture, mostly in developing countries.

Natural disaster shocks displace at-risk populations and affect migration patterns, either temporarily or permanently. The Global Estimates Report (Annual report by the International Displacement Monitoring Centre[50]) 2015 puts the annual average number of people displaced by natural disasters at 26.4 million from 2008 to 2015, equivalent to one person displaced every second. During the same period, an average of 22.5 million people are displaced by climate or weather-related disasters, or about 62,000 people per day. The same report further estimates that 16.7 million displaced people in Asia accounted for 87% of the global total in 2014, mostly in the Peoples Republic of China (PRC), India, and the Philippines. The persistent droughts in Bangladesh illustrate the wide-ranging effects on the country, which resulted in large-scale displacement and migration[51].

With more people displaced, internal migration increases primarily to urban areas, especially if economic conditions worsen in the affected areas and rebuilding and reconstruction takes years. The economic development in developing Asia has been characterized by increasing incomes and rapid urbanization. The region is becoming more urban with higher wage opportunities in cities, and more globalized as its share of world output and exports expand. As economic development is shown to lead to fewer fatalities from natural disaster-related events[47, 52, 53], it can be an important part of adaptation. Higher incomes mean the population can afford resilient housing and greater access to fast emergency response systems and financial instruments such as credit and insurance. However, whether urbanization has led to less damages and losses from disasters is unclear and the effect of migration on mitigating disaster losses is difficult to track. Choi[53] , for instance, shows that urbanization contributed slightly to the increase of disaster damages in countries of the Organisation for Economic Co-operation and Development from 1990 to 2010. On the other hand, Kahn[54] explores the role of market innovation in cities that may lead to higher quality and cheaper products to cope with disaster risks. He further adds that human ingenuity as well as individual locational and lifestyle choices can help urban populations to adapt.

3.2 Risk-Sharing

Unlike richer countries, poor and developing countries cope through other ways such as overseas development assistance. In one study, Yang[55] finds that greater hurricane exposure leads to large increases in foreign aid, especially in developing countries. Low-income countries also experienced a spike in migrant remittances but a decline in bank and trade-related lending. Within 3 years after hurricane exposure, total inflows amounted to roughly four-fifths of the estimated damages in these poorer subsamples. The opposite happens in richer countries where hurricane exposure leads to inflows of new lending from multilateral institutions but which are offset by a large decline in private financial flows. Said study provides the first evidence of country risk sharing and consumption smoothing during market volatilities and of some types of private financial flows that help buffer countries from negative economic shocks or exogenous shocks such as from hurricanes.

Although international aid can mitigate the effects of natural disasters, it may not be sustainable in the long term relative to the rebuilding costs and may also reduce the incentives to invest in adaptation. These shocks significantly increase the debt-to-GDP ratio as well, putting more pressure on developing economies[6]. Countries with financially developed marketswith greater access to credit and high insurance penetrationare usually high-income economies and can mitigate the economic cost of natural disasters without resorting to deficit financing of expenditures[56]. Felbermayr and Gröschl[5]show that a financially open economy can lessen the negative effects on GDP per capita. On average, output losses for financially less developed countries account for about 2%-10% of GDP. This further reinforces the assumption that adaptive

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capacity increases with income.

Insurance can also be an important form and substitute to cope with disaster risk, especially for developing countries. It offers a way to reduce the costs of disaster damage without raising taxes or reducing spending[13]. However, poor countries often lack access to disaster insurance. The World Bank's Global Index Insurance Facility is a new and innovative approach that addresses the lack of access to insurance in developing countries[57]. This index-based (or parametric index) insurance for loss of assets and capital due to natural disaster shocks is based on deviations from the normal values of weather parameters such as wind speed for tropical cyclones, precipitation and rainfall for droughts, and temperature for extreme temperature and heat waves. A multidonor trust fund, it has so far funded private sector insurance initiatives in Indonesia, Sri Lanka, and Papua New Guinea.

Catastrophic risk finance, or disaster risk finance, can also mitigate against natural disaster risks in Asia, as part of a comprehensive disaster risk management in the region. As early as 2008, the Asian Development Bank has been at the forefront of setting up this multilateral risk-sharing mechanism, patterned after the Caribbean Catastrophe Risk Insurance Facility. Opportunities exist for these types of risk sharing in the Asian region and are viable if done through regional publicprivate partnerships, albeit lacking capacity and resources[58]. The Pacific Catastrophe Risk Insurance Pilot started in 2013 is an example of an ongoing program that aims to increase the capacity of small Pacific island states for postdisaster financing and reconstruction needs.

In the 1990s, catastrophe bonds were issued to hedge against disaster-related risks. Pension funds and large institutional investors bought about four-fifths of issued catastrophe bonds in 2014, with higher returns than other securities. The outstanding amount is about USD25 billion with about USD8.8 billion issued in 2014 alone[14]. However, their long maturity, unwillingness of investors to take on the risks, and difficulties in estimating potential losses have dissuaded investors. They do not see the appeal of an investment whose name includes "catastroph"[59]. The huge losses of the insurance industry during Hurricane Katrina also tempered investors eagerness to invest. One thing they have discovered, however, is that a Katrina-type event went from a 1-in-40-year event to a 1-in-20-year event. The risk from natural disasters has doubled.

4 Policy Recommendations

Recognizing that climate change compromise development, numerous efforts on climate change adaptation and mitigation have been identified over the past several years. One of the targets of United Nation's Sustainable Development Goal 13[60] is " to strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries ".Designs and policy measures are country specific and very much dependent on each national circumstances and experiences. These measures must be integrated into national disaster plans as well as in medium- and long-term economic projections. International recommendations and policies on climate change must have proper support from the national government for them to be effectively and efficiently implemented.

International aid played a key role in the construction of disaster-resilient infrastructure in developing countries and development of resilient crop varieties. At the national level, policies and structures for disaster response are in place and preparedness is crucial to prevent large losses from natural disasters. In coordination with the private sector, governments must establish and invest more on early warning systems for natural hazards to warn and prevent large damages. Coordinated policies and mechanisms must be in place in order for the public sector, private sector, and other humanitarian organizations and affected local governments to achieve a proper and faster response and delivery of relief goods and services.

Redirecting investments toward adaptation measures as well as additional financing for climate-resilient initiatives can be done to cope with disasters. Developed and developing economies have to pool resources to better provide assistance both to prevent large damages and losses as well as in faster rebuilding.

Governments must also establish and maintain information management systems to properly identify and prioritize adaptive measures and create their own local adaptation and disaster risk reduction plans. They can further disseminate information and adaptation measures to help improve knowledge on the impact of climate change by mainstreaming climate awareness into the basic education curriculum. Capacity building down to the local level should be conducted especially in disaster-prone areas.

5 Conclusion

Natural disaster shocks, such as typhoons and droughts, have the potential to undo years of development by destroying both human and physical capital. Data from existing studies as well as from global disaster databases point to increasing damages and losses. Using exogenous indicators such as wind speed, temperature, and rainfall patterns, robust estimates point to significant short- and long-term losses to per capita growth, from as low as 0.1%-14.9% for typhoons and 0.01%-3% for droughts.

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The extent of output volatility is felt not only in the year of impact but in succeeding years as well, up to 5 years for droughts and 20 years for typhoons. In Asia, the elasticity of damages with respect to maximum wind speed is about 2. This would be higher if further research takes into account other factors such as storm surge and rainfall as well as including socioeconomic factors in future projections.

Current research points to more frequent and stronger weather shocks as the earth gets warmer. Together with temperature variation and sea level rise, the risks from climate-related natural disasters increase. In developing Asia, the macroeconomic impacts from both extreme temperatures and extreme weather events can significantly dampen the region's growth prospects and increase inequality. Vulnerable populations from disaster-prone areas are mostly the poor who have the least access to resilient housing, are most affected by volatile food prices through its effects on agricultural production, and have the least access to financial instruments such as credit and insurance.

Since the poor suffer the most from the effects of natural disaster shocks, adaptation efforts should address needs such as relocation, resilient infrastructure, new resistant crops, and government transfers to more sustainable ex ante strategies and risk-sharing mechanisms like disaster insurance.

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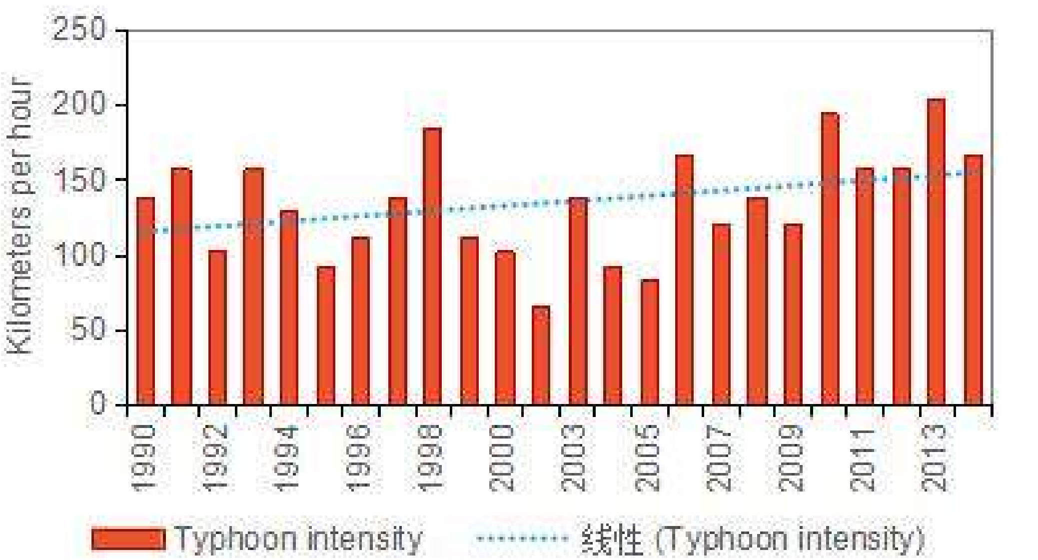
Appendix A Effects of Cyclones and Other Shocks to Gross Domestic Product Per Capita

Event Type	Effect on Income	Observed After	Probability of Occuring in a Single Year
Temperature increase (+1 °C)*[a]	–1.0%	10 years	6.40%
Temperature increase (>1 °C, SP5)**[b]	–23.0%	>20 years (by 2100)	…
Temperature increase (>1 °C, SP5)***[f]	–10.0%	>20 years (by 2100)	…
Civil war[c]	–3.0%	10 years	6.30%
Tax increase (+1% GDP)****[d]	–3.1%	4 years	†16.8%
1 standard deviation cyclone	–3.6%	20 years	14.40%
Currency crisis[c]	–4.0%	10 years	34.70%
Weakening executive constraints[c]	–4.0%	10 years	3.70%
90th percentile cyclone	–7.4%	20 years	5.80%
Banking crisis[c]	–7.5%	10 years	15.70%
Financial crisis[e]	–9.0%	2 years	<0.1%
99th percentile cyclone	–14.9%	20 years	0.60%

Note:…= data not available, GDP = gross domestic product, SSP5 = Shared Socio-economic Pathway 5. * Poor countries only. ** Poor and rich countries. *** Developing Asia only. **** United States only. Number of quarters with any tax change. [a] Dell, Jones, and Olken, 2012[21]; [b] Burke, Hsiang, and Miguel, 2015[61]; [c] Cerra and Saxena, 2008[62]; [d] Romer and Romer, 2010[63]; [e] Reinhart and Rogoff, 2009[64]; [f] 14 Lee, Villaruel, and Gaspar, 2016[22].
Source: Adapted from Hsiang S and Jina A[23].

Appendix B Intensity of Typhoons at Landfall in the Philippines, 19902014



Note: Source: Authors calculations using data from IBTrACS version v03r08. http://www.ncdc.noaa.gov/oa/ibtracs

Appendix C Average Effects a Year after Typhoon Exposure in the Philippines (%)

Outcome	Average Rate of Decrease
Household income	–6.6*
Household expenditures	–7.1
Meat	–12.5
Education	–13.3
Medical	–14.3
Female infant mortality	1 death per 1,000 live births

Note:* Compared against average savings rate of 15% in 2009. Source: Antilla-Hughes, Jesse Keith, and Solomon Hsiang[40].

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