Mitig Adapt Strateg Glob Change
DOI 10.1007/s11027-016-9731-y

ORIGINAL ARTICLE

A global assessment of adaptation investment from the perspectives of equity and efficiency

Chen Chen[1,2,3] · **Jessica Hellmann**[4] · **Lea Berrang-Ford**[5] · **Ian Noble**[1,6] · **Patrick Regan**[1,7]

Received: 9 June 2016 / Accepted: 21 November 2016

Abstract Equity and efficiency should be considered when allocating resources for climate change adaptation. More than a decade after the Least Developed Countries Fund approved adaptation funds for 18 countries in 2003, it is possible to take the stock of investment data and to test empirically whether equity and efficiency have been factored into adaptation investment decision-making. To evaluate equity, one must determine if resources were distributed to areas of greatest need. Vulnerability assessments provide information on the global distribution of the need for adaptation. To evaluate efficiency, one must compare cost and benefit of an investment. Although it is difficult to assess ex-ante the cost and benefit of investment strategies, it is possible to measure efficient use of expenditures with readiness assessment, as a metric of capacity to deploy adaptation resources. We used vulnerability and readiness measures of the Notre Dame Global Adaptation Initiative (ND-GAIN) Country Index as proxies of equity and efficiency. This article quantitatively interrogates—through the lens of public fund allocation—the roles of vulnerability and readiness in shaping adaptation investment decisions. Our findings suggest that countries facing increasing impacts from climate change have received more adaptation investments from international sources than countries with less vulnerability. Further, international investments also preferentially flow to countries that are more ready to deploy adaptation resources. Since the most vulnerable countries are likely to be less ready for investment, our findings support the efforts to improve the investment

✉ Chen Chen
cchen8@nd.edu

[1] Notre Dame Global Adaptation Initiative, University of Notre Dame, Notre Dame, IN, USA

[2] Notre Dame Initiative for Global Development, University of Notre Dame, Notre Dame, IN, USA

[3] 1400 East Angela Blvd., South Bend, IN 46617, USA

[4] Institute on the Environment, University of Minnesota, Minneapolis, MN, USA

[5] Department of Geography, McGill University, Montreal, Quebec, Canada

[6] Climate Change Institute, Australian National University, Canberra, Australia

[7] Department of Political Science, University of Notre Dame, Notre Dame, IN, USA

Published online: 13 December 2016

potential of the most vulnerable countries by investing first to enhance their readiness, in order to unlock adaptation solutions.

Keywords Adaptation Investment · Assessment · Climate change · Readiness · vulnerability

1 Introduction and background

Substantial climate change over the next several decades is highly likely even with marked reductions in greenhouse gas emissions (IPCC WGI SPM 2013). A changing climate is projected to increase climate-related natural disasters (IPCC SREX SPM 2012), increase costs for businesses (Margulis et al. 2011; Surminski 2013), alter patterns of food production (Wheeler and Von Braun 2013; Lesk et al. 2016), change the types, frequencies, and locations of infectious diseases (Lindgren et al. 2012; WHO 2014), and generally threaten lives and livelihoods around the world (IPCC WGII SPM 2014). Thus, creating strategies to make countries and communities more climate-resilient and finding ways to effectively support and prioritize adaptation to climate change (hereafter "adaptation") have become important goals (COP13 2007; COP21 2015).

Adaptation is the process of adjusting to a changing climate (IPCC WGII Glossary 2014), a process that comes with a range of costs and a need for financial investment from the public and private sectors (Economics of Climate Adaptation Working Group 2009; UNEP 2016). Equity and efficiency have been considered important criteria that shape decisions of where and how to finance adaptation actions (Aakre and Rübbelke 2010; Barr et al. 2010; Persson and Remling 2014; Remling and Persson 2015).

From an equity point of view, investment must be directed to locations where the impacts from climate change are projected to be larger, in other words, where adaptation finance is more critical (e.g., Paavola and Adger 2006; Grasso 2010; Barr et al. 2010) . Vulnerability reflects the propensity or predisposition of human societies to be negatively affected by climate hazards (IPCC WGII Glossary 2014). In practice, climate change vulnerability assessment has already been used to guide investment for adaptation actions (e.g., Feenstra et al. 1998; Metzger 2005; Cruce 2009; Oregon Department of Transportation 2014).

From an efficiency point of view, investment must be directed where resources could yield more benefits for each unit of cost (Mendelsohn 2000; Aakre and Rübbelke 2010). The direct evaluation of costs and benefits is usually difficult ex-ante, however, due to uncertainty of climate impacts and low comparability across projects and entities (Persson and Remling 2014). Yet, it is possible to anticipate an efficient use of the investment by examining the capacities that help put resources to good use for adaptation, something we call "readiness."

Readiness has recently been conceptualized as capacity to plan for, access, deliver, and monitor and report on adaptation funds (Vandeweerd et al. 2012). Based on this concept of readiness, global adaptation financing entities, including Adaptation Fund (AF) and Green Climate Fund (GCF), started Readiness Programme to fund preparatory activities that help developing countries to better receive and manage the funds (AF 2014; GCF 2015), mainly to enhance institutional capacities for receiving and using adaptation funds. We attempt to conceptualize readiness, however, related to a suite of capacities beyond institutional capacities and for both public and private finance. There is not a well-developed literature for measuring readiness in a broader sense, but similar concepts have been used in relation to investment and development aid. For example, one measure of investment readiness used by the European Commission (EC) seeks to measure the ability of small and medium businesses to make use of external finance. EC's readiness measure includes the ability to

create a competitive investment climate, to provide appropriate structures and relevant information for investors, and to create investors' confidence (European Commission 2006). A second example is the Country Policy and Institutional Assessment (CPIA) measure, which assesses key policy and institutional elements within a country's control that will allow it to use development assistance efficiently (IDA 2007). A third example is absorptive capacity, reflecting organizational features that accelerate the internalization of acquired knowledge and information (Zahra and George 2002). The concept of absorptive capacity has been adopted by studies on foreign direct investment (FDI), to represent a range of processes that enhance the use of external investment (Girma 2005). Drawing on these examples, our readiness measure has three key components to assess how ready a locality is to make efficient use of adaptation investment: (1) sound investment environments, (2) strong institutional supports, and (3) potent absorptive capacities.

While theories and practices of strategizing adaptation investment decisions are being advanced, there is little evidence whether existing investment has considered equity and efficiency. More than a decade after the Least Developed Countries Fund approved $4 million or so for adaptation projects in 18 countries, it is now possible to test whether vulnerability and readiness are predictors of the adaptation investments already in place (UN FCCC 2004). This article quantitatively interrogates—through the lens of public fund allocation—the roles of vulnerability and readiness in shaping adaptation investment decisions. We additionally discuss and critically appraise global patterns of the investment in order to inform strategies for global investment decision makers. We use the metrics in the Country Index of the Notre Dame Global Adaptation Initiative (ND-GAIN) to measure vulnerability and readiness at the country level.

2 Methods

Based on a survey of the literature on vulnerability and readiness assessments, in our Country Index framework, we defined vulnerability as a function of three components: exposure, sensitivity, and adaptive capacity (Table 4 in Appendix 1), recognizing that a more recent thinking suggests that exposure may be treated separately from vulnerability per se (IPCC WGII SPM 2014). Our framework conceptualizes vulnerability across six sectors that reflect key aspects of human lives and livelihoods: (1) food, (2) water, (3) health, (4) ecosystem services, (5) human habitat, and (6) infrastructure. For readiness, our Index assesses the capacity to efficiently deploy adaptation investment regardless of sources, by three components: (1) economic readiness, reflecting the business environments that make a society attractive for investment; (2) governance readiness, reflecting the institutional and governance supports that help investment grow without major interruption; and (3) social readiness, reflecting the social capacities that facilitate the effective use of investment (Table 5 in Appendix 1).

Our Country Index framework is composed of 45 indicators in total for the sectors and components above. These indicators quantify different aspects of both vulnerability and readiness (Tables 6 and 7 in Appendix 2). The Index scores vulnerability and readiness for 180 of the 193 UN countries from 1995 to 2014, following the formula:

$$\text{Vulnerability} \quad \text{score} = \frac{1}{6} * \sum\nolimits_i \text{Sector}_i \,\text{score}$$

$$\text{Readiness} \quad \text{score} = \frac{1}{3} * \sum\nolimits_j \text{Component}_j \,\text{score}$$

Vulnerability and readiness scores range from 0 to 1, with 1 representing the most vulnerable and the most ready cases. Sector and component scores are computed by aggregating standardized indicator scores. This standardization followed a "proximity-to-reference value" approach that first identifies upper and lower reference values for each indicator and, second, scales each indicator to a 0–1 range proportional to the distance from the reference value. Reference values were identified in two ways. First, we adopted existing, well-accepted goals for the indicators of social service access or the indicators that are development goals themselves. For example, the reference value for the sanitation access indicator is 100% (United Nations 2015) and that for fixed broadband Internet subscription is 60% (International Telecommunication Union 2013). Second, for other indicators without accepted goals, we used the data on the best performing country or countries as reference value for each indicator to reflect the lowest degree of exposure or sensitivity or the highest adaptive capacity and readiness. However, whenever possible extreme outliers result in highly skewed scores, we used the 10th or the 90th percentile values.

We selected two country-level investment variables as outcome variables. The first variable was acquired from Climate Funds Update (CFU), a joint initiative of the Heinrich Böll Stiftung and the Overseas Development Institute, to track the climate finance flow including the funds for adaptation. CFU systemically records information of each approved investment, including the recipient country, the year when investment decision was made, and the dollar amount of the investment (Climate Funds Update 2016, http://www.climatefundsupdate.org/about/data-figures-notes). These investments are public funds approved by multinational donors and multilateral or bilateral agencies since 2003. The CFU reports both the approved and disbursed amounts, and we used the approved amount to reflect the investment decisions. We excluded the investments that fund regional projects, focusing on the investment decisions for explicit individual countries.

The CFU dataset covers international investment flows to developing countries, or non-Annex I countries, while developed countries predominately rely on domestic financial resources for adaptation (OECD 2015). To include both developed and developing countries as well as to capture adaptation investment made domestically, we selected a second outcome variable, the Adaptation Initiative Index (AII) developed by Tracking Adaptation to Climate Change Consortium (TRAC3). TRAC3 counted the number of country-level adaptation initiatives documented in national reporting to the United Nations Framework of Convention on Climate Change through the National Communications (Berrang-Ford et al. 2014; Lesnikowski et al. 2015; Lesnikowski et al. 2016). AII breaks down adaptation initiatives into *groundwork*, those actions that are critical for informing climate change risks and preparing for adaptation, and *adaptation*, those actions that aim to tangibly reduce climate vulnerability. TRAC3 took data from 2008 to 2012 for AII with a global coverage. We used AII's *adaptation* score (ranging from 0 to 19) in our analysis as a proxy of the scale of the domestic investment, given that countries that have scored higher in AII *adaptation* have more implemented and thus funded adaptation initiatives. The next step is to model the two outcome variables separately (called "CFU model" and "AII model" hereinafter), using vulnerability and readiness measures as core predictor variables.

We split the measure of vulnerability in the ND-GAIN Country Index into projected biophysical climate vulnerability and current social vulnerability (Cutter et al. 2012), to differentiate the sources of vulnerability. The Country Index's exposure score measures the degree to which the future climate change is projected to affect a country's life-supporting sectors according to climate projections and impact models (Chen et al. 2015). We quantified

the social vulnerability by averaging the score of the sensitivity measure and the score of the adaptive capacity measure.

Other than the vulnerability and readiness measures, we included two other groups of measures as control variables (Table 1). First, we included a country's experience in past climate disasters, assuming that the assessment of needs for adapting to future climate takes into account the experience from historical events. Both literature and adaptation practice have called for integration of disaster risk management and adaptation (e.g., Thomalla et al. 2006; Mercer 2010; Hay 2012; IPCC SREX SPM 2012). And there is opportunity to create synergies in international finance for both (IPCC SREX SPM 2012). So we hypothesize that the frequency and the impact of disaster events under the current climate may influence adaptation investment. Two variables were chosen for this group. One measures the number of disasters as a proxy of the degree to which a country has been prone to these disasters. The data was collected from The International Disasters Database (EMDAT), which reports the occurrence of a range of nature disasters since 1900. We focused on climate disasters from 1985, including drought, extreme temperature, flood, storm, and wildfire, and we aggregated the number of occurrence for each type of climate disasters. Another variable is Germanwatch's Climate Risk Index (CRI), which was used as a proxy of the overall risks of the major climate disasters in the past. CRI scores countries according to the material and human losses from weather-related events. Countries that have been less affected by the recorded events have higher scores. The second group of control variables summarizes the country resources, which could be lacking in less developed countries for adaptation. Adaptation finance is called to be mainstreamed with development assistance (Schipper 2007; Stockholm Environment Institute 2008; Klein 2010) and has in practice been partly channeled through development agencies

Table 1 Variables included in the models of adaptation investment

Variables	Date for the CFU model	Date for the AII model	Data source
Dependent (outcome) variables			
Adaptation investment			
Amount of approved investment from multilateral, bilateral, and multinational donors (CFU)	2003–2014		CFU
AII *adaptation* score		2008–2012	TRAC3
Core-independent (predictor) variables			
Climate change vulnerability			
Future biophysical vulnerability score	*After* 2020	*After* 2020	
Social vulnerability score	2003–2014	2008–2012	ND-GAIN
Adaptation investment readiness			
Readiness score	2003–2014	2008–2012	ND-GAIN
Control variables			
Historical climate disaster events			
No. of occurrence of climate disasters	1985–2003	1985–2008	EMDAT
Global Climate Risk Index score	1991–2010	1991–2010	Germanwatch
Economic resources			
GDP, PPP (current international $)	2003–2014	2008–2012	World
Population, total	2003–2014	2008–2012	Development
GNI per capita, PPP (current international $)	2003–2014	2008–2012	Indicators

according to recent studies (e.g., Donner et al. 2016; Mostafa et al. 2016). So we hypothesize that country resources could be important factors when making adaptation investment decisions. We used country size (population), economy size (Gross Domestic Production), and the economic development status(Gross Net Income per capita) as three control variables to represent country resources (Berrang-Ford et al. 2011; Lesnikowski et al. 2013). These data were collected from the World Development Indicators.

While both two predictors need to be retained for the purpose of this paper, to avoid collinearity among the control variables, we examined the correlation of pairs of proposed variables to decide the inclusion of them in the model. We excluded those that have strong and significant correlation with other controls ($r > 0.5$ and $p < 0.1$) and retained three for inclusion in the model: CRI, total population, and GNI per capita. Tables 8 and 9 (Appendix 3) shows the correlation results.

We systematically modeled the two adaptation investment variables by first examining the unadjusted effects for each predictor variable, one at a time, and second including all the control variables. Ordinary linear regression was used for the CFU model. To model the AII variable that includes count data, we used generalized linear regression assuming a Poisson distribution.

3 Results

To understand the roles that vulnerability and readiness have played in shaping investment decisions, we first examined the relationship between the two. As readiness is a measure of the capacities to use adaptation investment, would higher readiness yield more benefit in terms of vulnerability reduction? We examined the 20-year average readiness scores from 1995 to 2014 and the changes in vulnerability score over the same period of time (Fig. 1). Overall, countries with higher average readiness scores tend to have more reduction in vulnerability over time. This is especially the case for countries with lower development status. Specifically, the correlation between readiness and vulnerability reduction is statistically significant for lower-income countries (composed of lower-middle income and low-income countries according to the classification of country incomes, World Bank 2016) ($r = -0.25$, $n = 79$, $p < 0.001$), but not higher-income countries (Fig. 1). It may be because higher-income countries have already in a lower level of vulnerability compared to the rest of the world so low-hanging fruits may have already been taken and the further reduction in vulnerability becomes harder (Hallegatte et al. 2016).

We then built two models based on the two dependent variables, AII's *adaptation* score and the approved international adaptation investments according to CFU. The AII model highlights the roles of resources and capacities in making decisions about domestic adaptation investment. This can be seen from two observations by the results in Table 2. First, investment decreases as social vulnerability score increases or readiness score decreases. Social vulnerability is a strong and significant predictor when GNI per capita, a measure of economic development status, is controlled (model 2 vs. model 6 and model 8, Table 2), and the effect of development becomes insignificant when social vulnerability is included in the model (model 4 vs. model 6 and model 8, Table 2). In the full model (model 8, Table 2), a 0.1-point increase of social vulnerability score results in about 20% reduction (exp(0.1813) = 1.199) of the number of reported adaptation initiatives, a proxy of the decrease in investment. Similarly,

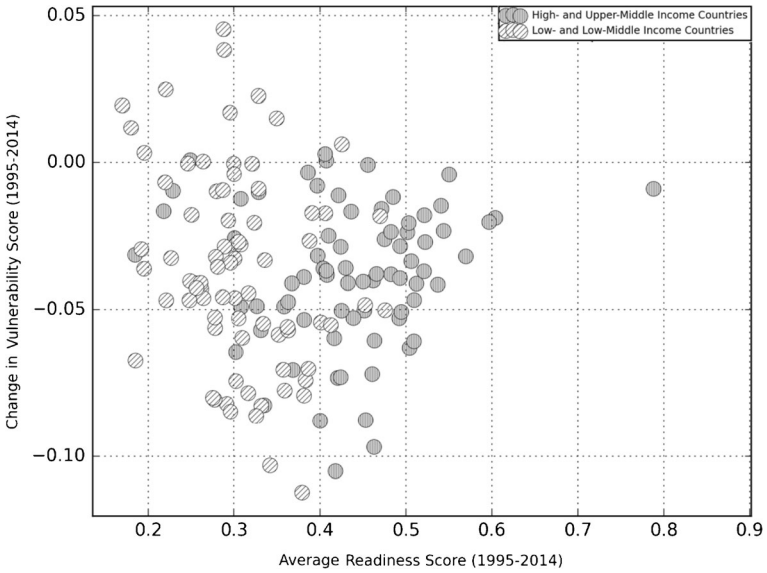

Fig. 1 Average readiness and the change of vulnerability (delta value), from 1995 to 2014; each *dot* represents one country. The countries are grouped according to the relative economic development status: (1) higher-income group composed of high-income countries and upper middle income countries and (2) lower-income group composed of low-income and lower-middle income countries according to the World Bank (2016) (data source: Notre Dame Global Adaptation Initiative)

the effect of readiness is strong and significant regardless of the inclusion of development in the model (model 3 vs. model 7 and model 8, Table 2), but the significant effect of development (model 4, Table 2) disappears when readiness is in the model (model 7 and model 8, Table 2). In the full model (model 8, Table 2), a 0.1-point increase of the readiness score results in a 15.1% increase (exp(0.1407) = 1.151) of the investment. Second, the proxies of the adaptation needs are not significant in the model. Biophysical vulnerability score does not show to be a stable predictor in the model (model 1 vs. model 5 vs. model 8, Table 2), and CRI is statistically insignificant in all models (models 4–8, Table 2). These two observations suggest that what have driven domestic adaptation investment are mainly resources and capacities, more than the needs for adaptation.

The CFU model shows that both vulnerability and readiness are strong predictors of the investment decisions that have been made internationally (Table 3). First, we found that the investment for adaptation increases with biophysical vulnerability (Tables 4, 5, 6, 7, 8, and 9). The effect of this variable is fairly consistent between the unadjusted model and the multivariate models (model 1 vs. model 5 and model 8, Table 3). In the full model (model 8, Table 3), keeping other independent variables constant, for each 0.1 points the biophysical vulnerability score increases and adaptation investment increases by 38.7% (exp(0.3275) = 1.387). Second, we found that the effect of social vulnerability varies between the unadjusted and the multivariate models (model 2 vs. model 6 and model 8, Table 3). Even though social vulnerability is a significant predictor in model 2 (Table 3), when development status is included, the effect disappears (model 6 and model 8, Table 3). Thus, social vulnerability is a significant predictor alone but not when development is included in the model. Considering that countries socially less vulnerable are generally more developed, our result suggests that poorer countries receive more global funding than richer countries; however, for two countries

Table 2 Modeling adaptation investment (the AII model. Outcome variable: adaptation score, Adaptation Initiative Index 2008–2012)

	Unadjusted model			Multivariate model				
Dependent (outcome) variable: AII's *Adaptation* score	Model 1 (future biophysical vulnerability)	Model 2 (social vulnerability)	Model 3 (readiness)	Model 4 (historic disasters + development + population)	Model 5 (future biophysical vulnerability + historic disasters + development + population)	Model 6 (social vulnerability + historic disasters + development + population)	Model 7 (readiness + historic disasters + development + population)	Model 8 (full model: future biophysical vulnerability + social vulnerability + readiness + historic disasters + development + population)
Core independent (predictor) variables								
Biophysical vulnerability score	−0.118 (0.876)				0.923 (0.297)			2.641*** (0.009)
Social vulnerability score		−1.679**** (0.000)				−1.656** (0.044)		−1.813* (0.059)
Readiness score			1.101**** (0.000)				1.308** (0.013)	1.407** (0.015)
Control variables								
Climate Risk Index score				−0.00207 (0.174)	−0.00224 (0.141)	−0.00109 (0.495)	−0.00159 (0.304)	−0.000962 (0.546)
Gross national income per capita (log)				0.129*** (0.007)	0.153*** (0.004)	−0.0307 (0.740)	−0.0468 (0.581)	−0.160 (0.121)
Total population (log)				0.0176 (0.560)	0.0236 (0.436)	−0.0163 (0.638)	0.0226 (0.459)	0.00144 (0.967)
Constant	1.305**** (0.000)	1.930**** (0.000)	0.681**** (0.000)	−0.0383 (0.956)	−0.776 (0.430)	2.589* (0.079)	0.799 (0.299)	1.609 (0.285)
Observations	116	116	113	109	109	109	109	109
Bayesian information criterion	511.2	491.9	481.7	472.7	476.3	473.3	471.2	472.5

p Values in parentheses

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$; ****$p < 0.001$

that are equally poor, countries with more social vulnerability to climate change do not receive more funding than those that are less vulnerable. Third, readiness (model 3 vs. model 7 and model 8, Table 3) is a significant predictor (model 3, Table 3). When controlling for GNI per capita, the sign of coefficient changes from negative in model 3 (Table 3) to positive in model 7 (Table 3). Considering that more ready countries are generally more developed, our result suggests that poor countries receive more global funding than richer countries. But when development status is the same, who is more ready receives more funding. In the full model (model 8, Table 3), a 0.1-point increase of the readiness score implies a 36.8% increase (exp(0.3137) = 1.368) in the amount of investment.

4 Discussion

While the international communities have pledged more resources to support adaptation actions, there is little known so far on how the investments previously have been made for adaptation. As it is deemed proper that adaptation investment should be equitable and efficient, it is especially important to understand if investments made in the past have factored equity and efficiency into the decision-making. Provision of empirical evidence has been limited by data availability and due to lack of appropriate proxies of equity and efficiency. The ND-GAIN Country Index's vulnerability and readiness measures were employed in this paper to explore the patterns of adaptation investment. Our analysis suggests that both equity and efficiency have shaped the adaptation investment decisions made internationally.

The available international investment datasets (CFU data) allow an analysis of the investment from public sectors. The AII and CFU models both suggest that readiness, an assessment of investment efficiency, is a strong predictor of investment in both developing and developed countries. Higher readiness is associated with higher investment amount. Also, social vulnerability is statistically a significant predictor in the AII model, but negatively correlated with the amount of domestic adaptation initiatives, the proxy of domestic adaptation investment in our analysis, suggesting that less vulnerable countries invest more on adaptation. This sounds counterintuitive, as less vulnerable countries are likely to have less need to adapt. And the degree to which countries will be and have been exposed to climate risks are not a strong predictor based on the AII model, further demonstrating that the investment for domestic adaptation may less be a function of needs but more of a function of resources and capacities. Low vulnerability is indicative of less need for adaptation, but it is also an indication of high capacity at present that enables more cost-intensive adaptation actions, including further organizational developments, further improvement of public awareness and outreach, more surveillance and monitoring of activities, and so forth (Lesnikowski et al. 2015). Therefore, the AII model shows the significance of countries' own capacities and resources for investing on adaptation initiatives. Usually more developed countries are likely to have more of these capacities and resources, generated by economic development to enhance resilience to many different stressors including those arising from climate change (e.g., Adger et al. 2003; Agrawala 2004; Bird and Glennie 2011; Inderberg et al. 2015).

This highlights the importance of equity when allocating investment internationally, to provide support for vulnerable countries that lack resources of their own. The CFU model shows that equity is indeed taken into consideration when making global investment decisions. We found that the international investments have been targeted to help the countries that are likely to suffer more biophysical impacts from climate change and also targeted to those

Table 3 Modeling adaptation investment (the CFU model. Outcome variable: international adaptation funds approved 2003–2014)

	Unadjusted model			Multivariate model				
Dependent (outcome) variable: amount of approved investment from multilateral, bilateral, and multinational donors (CFU)	Model 1 (future biophysical vulnerability)	Model 2 (social vulnerability)	Model 3 (readiness)	Model 4 (historic disasters + development + population)	Model 5 (future biophysical vulnerability + historic disasters + development + population)	Model 6 (social vulnerability + historic disasters + development + population)	Model 7 (readiness + historic disasters + development + population)	Model 8 (full model: future biophysical vulnerability + social vulnerability + readiness + historic disasters + development + population)
Core independent (predictor) variables								
Biophysical vulnerability score	3.586** (0.023)				2.837* (0.053)			3.275** (0.026)
Social vulnerability score		2.488*** (0.001)				−0.578 (0.646)		0.250 (0.854)
Readiness score			−2.554** (0.016)				2.566* (0.067)	3.137** (0.042)
Control variables								
Climate Risk Index score				−0.00926**** (0.000)	−0.00936**** (0.000)	−0.00911**** (0.000)	−0.00822**** (0.000)	−0.00815**** (0.000)
Gross national income per capita (log)				−0.616**** (0.000)	−0.572**** (0.000)	−0.679**** (0.000)	−0.801**** (0.000)	−0.757**** (0.000)
Total population (log)				−0.0210 (0.610)	−0.000436 (0.992)	−0.0320 (0.503)	−0.00423 (0.923)	0.0381 (0.492)
Constant	7.713**** (0.000)	8.173**** (0.000)	10.44**** (0.000)	15.76**** (0.000)	13.67**** (0.000)	16.75**** (0.000)	16.02**** (0.000)	13.00**** (0.000)
Observations	111	112	109	108	107	108	107	107
Adjusted R^2	0.038	0.086	0.044	0.346	0.366	0.341	0.364	0.383
Bayesian information criterion	330.4	326.8	325.3	289.8	288.1	294.2	288.6	292.4

p Values in parentheses

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$; ****$p < 0.001$

countries that are more economically disadvantaged and thus less self-sufficient to support adaptation.

However, vulnerable countries tend to be also less ready according to ND-GAIN's Vulnerability-Readiness Matrix (ND-GAIN 2015, also see Appendix 4). Notably, these countries are concentrated in Sub-Saharan Africa and South Asia where there are more least developed countries than other regions of the world. These countries are likely to endure significant human suffering under climate change, unless funding moves quickly to improve the ability to adapt. However, because of low readiness, the investment made there may not be highly efficient, which could inhibit the inflow of adaptation funds that strive to meet the balanced investment goals to be both equitable and efficient. All the other countries in the Matrix (ND-GAIN 2015, also see Appendix 4) are either in a more favorable condition to attract public funds or even private sector investment due to high readiness (upper-right quadrant), not urgently need resources for adaptation because of low vulnerability (lower-left quadrant), or are self-sufficient enough to generate resources internally to support needed adaptation actions (lower-right quadrant). What should be done for the first group of countries to eventually mobilize resources and reduce vulnerability to climate change?

Given the relationship between readiness and vulnerability reduction (Fig. 1), capacity building to enhance readiness can be a key to unlock adaptation solutions, especially for economically less advantaged and climatically more vulnerable countries. Our results suggest the importance of providing support that helps to strengthen readiness, preceding or in parallel with investing in adaptation, a step taken by many global funders (e.g., GIZ 2013; AF 2014; CIF 2015; GCF 2015). Even though the readiness conceptualized here is a more comprehensive measure than these programs, investing to enhance the efficiency of adaptation is an important move as the world allocates funding for vulnerability reduction.

Our findings highlight the roles of vulnerability and readiness as predictors of international adaptation investment decisions. Because equity and efficiency are both taken into account when investing on adaptation at a global scale, as we found, the efficiency consideration may be a barrier for the most vulnerable, yet least ready countries to get financial resources that are needed. Our findings explicitly support the global efforts to improve the investability of the most vulnerable country groups by investing first to enhance their readiness.

Acknowledgements The ND-GAIN's Country Index was built based on the groundbreaking work done at the Global Adaptation Institute in Washington DC. Special thanks are given to Bruno Sánchez-Andrade Nuño, who contributed his technical talents during the earlier years of the Index. Authors also want to give thanks to Notre Dame graduate students and supporting staffs who have been held accountable for the project in many fronts: Martin Murillo, Milan Budhathoki, Jishan Liao, Benjamin Mayala, and Alexandra Gumm. This work was done with tremendous supports from many foremost intellectual leaders in the field of climate change and adaptation. Authors are grateful to the following: Dennis Bours from the Global Environmental Facility, Cyril Caminade from the Liverpool University, Nitesh Chawla from the Department of Computer Science at Notre Dame, William Cheung from the University of British-Columbia, Michael Clark from the University of Michigan, Joyce Coffee from Climate Resilience Consulting, James Ford from McGill University, Francis Gassert from World Resource Institute, Patrick Gonzalez from the US National Park Service, Martina Grecequet from University of Minnesota, Alan Hamlet from the College of Engineering at Notre Dame, Alexandra Lesnikowski from McGill University, David Lodge from the Cornell University, Edwin Michael from the Department of Biological Science at Notre Dame, Patrick Murphy from Palo Alto Research Center, Mark Musumba from the Earth Institute, Felix Portmann from Goethe-Universität, Tien Shiao from H&M, Claudia Tebaldi from National Center of Atmospheric Research, and Abigail Wozniak from the Department of Economics at Notre Dame.

Appendix 1. Literature review for vulnerability and readiness assessments

Table 4 Methodologies for quantifying the components of vulnerability

Component of vulnerability	Definition in the ND-GAIN framework	Quantification methodologies	Features of methodology	Examples
Exposure	The extent to which human society and its supporting sectors are stressed by the future changing climate conditions (Adger 2006; Cutter et al. 2012). Exposure in the Index captures the physical factors external to the system that contribute to vulnerability (Füssel 2005).	Using recent historical data to describe the exposure to the current hazards	The use of historical data provides a rapid assessment of the current climate stresses, but not applicable to measure the future climate conditions for a forward-looking framework.	Krishnamurthy et al. (2014); Kreft et al. (2015)
		Using projections of future climates from climate models	Temperature, precipitation, and other climate projections provide a general indication of future climate conditions; however, they do not provide direct estimates of the climate impacts on human societies.	Yohe et al. (2006); Nogués-Bravo et al. (2007); Allison et al. (2009)
		Estimating the future hazard in various sectors, using statistical or mathematical models.	Sectoral-specific measures estimate the physical impacts of climate change on human societies. However, data and models are not universally available for all sectors of a society.	Statistical modeling: Lobell and Burke (2010); Wheeler (2011); Hajat et al. (2014) Mathematical modeling: Vörösmarty et al. (2000); Sullivan and Meigh (2005); Thow and De Blois (2008); DARA and Climate Vulnerable Forum (2012); Young et al. (2015); Balica et al. (2012); Suk et al.(2014)
Sensitivity	The degree to which people and the sectors they depend upon are affected by climate related perturbations (Smit et al. 2000; Kelly and Adger 2000;	Measuring the degree of dependency on sectors that are climate-sensitive	A livelihood-centered measure, the sensitivity assessment following this methodology reflects how livelihoods in a society	O'Brien et al. (2004); Allison et al. (2009); Cinner et al. (2012)

Table 4 (continued)

Component of vulnerability	Definition in the ND-GAIN framework	Quantification methodologies	Features of methodology	Examples
	Füssel 2005; Adger 2006)		are sensitive to climate perturbations.	
		Measuring proportion of populations sensitive to climate hazard due to factors such as topography and demography	A population-centered measure, the sensitivity assessment following this methodology reflects how populations in a society are sensitive to climate perturbations.	Adger et al. (2004); Schewe et al. (2014)
Adaptive capacity	The ability of society and its supporting sectors to adjust to reduce potential damage and to respond to the negative consequences of climate events (Yohe and Tol 2002; Brooks and Adger 2005; Brooks et al. 2005; Smit and Wandel 2006; Preston et al. 2009)	Measuring contextual capacity that reflects the socioeconomic conditions that enable human societies to deal with climate change impacts	This method assesses resources available in a society for adaptation including human and social capital, financial resources, institutional capacity, and access to energy, information, and social networks.	Adger et al. (2004); Twomlow et al. (2008); Kates et al. (2012)
		Measuring specific capacity that reflects a collection of means, readily deployable to deal with sector-specific climate change impacts	This method assesses current capacities that a society has to cope with climate pressures for specific sectors, either by individuals or by regional, national, and international actors.	Butt et al. (2005); Naylor et al. (2007); Tubiello and Rosenzweig (2008); Meza et al. (2008); (Mutekwa 2009); Deressa et al. (2009); Lindner et al. (2010); Piao et al. (2010)
		Mix of the contextual measure and specific measure	A mix of measures that captures both the specific capacities and the general socioeconomic conditions that enable a society to take on specific actions to address climate change impacts for different sectors.	Brenkert and Malone (2005); Yohe et al. (2006); Allison et al. (2009); ESPON Climate (2011); Aversano-Dearborn et al. (2011); Engle (2011); Krishnamurthy et al. (2014)

Appendix 2. Summarizing ND-GAIN country index metrics

Table 5 Methodologies for quantifying the components of readiness

Component of readiness	Definition in the ND-GAIN framework	Quantification methodologies used in the index framework	Features of the methodology	Examples
Economic readiness	The business environment that facilitates mobilizing capitals	The Ease of Doing Business Index, to evaluate quality of business regulation	The survey-based evaluation system scores the business regulations applied to different stages of business life cycle, based on the degree to which regulation eases or burdens business operation.	Economic Freedom Index (Heritage Foundation, 2016); Mina (2007); Flamini et al. (2009); Klapper and Love (2010)
Governance readiness	The stability of the society and institutional arrangements that contribute to the investment risks. A stable country with high governance capacity reassures investors that the invested capitals could grow under the help of responsive public services and without significant interruption	The Worldwide Governance Indicators, to evaluate the capacities of governance as part of the business environment assessment	The scoring of governance capacities synthesizes hundreds of existing variables and data including CPIA. These data reflect views on governance from experts worldwide in public and private sectors, as well as from NGO.	Ocean Health Index (Halpern et al. 2012); (Barr et al. 2010); (Buchanan et al. 2012)
Social readiness	Social conditions that help society to make efficient and equitable (Barr et al. 2010) use of investment and yield more benefit from the investment	Indicators that reflect quality of human capital, degree of social equity, innovation capacity, and infrastructure for learning and information access, to evaluate the social conditions under which investment can make more positive impacts	Indicators to measure social readiness are proxies for key features of a society that strengthen capacities to absorb investment and generate positive impacts	Addison and Heshmati (2003); Blömstrom and Kokko (2003); Barr et al. (2010); Farole and Winkler (2012)

Table 6 Rationale of the vulnerability indicators in ND-GAIN Country Index

Sectors of which vulnerability is measured	Exposure measures	Sensitivity measures	Adaptive capacity measures
Food (6 indicators)	Impacts of changing climate on food supply, and the challenge to meet the growing food demand	The degree to which a society and its population are sensitive to the declining food production and food market volatility	Capacities to provide food security for its population
Water (6 indicators)	Impacts of changing climate on the changing supply of freshwater	The degree to which a society and its economy are sensitive to the scarcity of freshwater supply	Capacities to reduce the impact of water scarcity on water security
Health (6 indicators)	Impacts of changing climate on infectious diseases	The degree to which a society and its population are sensitive to public health crisis	Capacities to provide public health-related services
Ecosystem service (6 indicators)	Impacts of changing climate on biodiversity	The degree to which a society and its economy are sensitive to the loss of natural capital and ecological assets	Capacities to protect ecosystem and biodiversity under stresses
Human habitat (6 indicators)	Impacts of changing climate on magnitude of extreme weather	The degree to which a society and its population are sensitive to the negative impact of extreme weather events	Capacities to maintain the normal functions of human society in facing extreme weather
Infrastructure (6 indicators)	Impacts of changing climate on infrastructural capacity	The degree to which a society and its population are sensitive to coastal hazards and energy market volatility	Capacities to mitigate the impact of climate extremes on standing infrastructure

Table 7 Rationale of readiness indicators in ND-GAIN Country Index

Components of readiness measure	Indicators	Rationale
Economic readiness (1 indicator)	Ease of Doing Business Index (DB), composed of 10 sub-indices	DB index is a proxy of the quality of business regulation (Djankov et al. 2004). Countries with easy and flexible environment ensure smooth operations of business therefore attract investment. The index therefore provides support for adaptation investment decisions.
Governance readiness (4 indicators)	Worldwide Governance Indicators (WGI)	WGI provide proxies to capture institutional and governance capacities (Kaufmann et al. 2011). Countries scored high by WGI have good performance in policies and institutional arrangements. They can provide investors a safe, transparent, and appropriately regulated system to use adaptation investment and support adaptation actions.
Social readiness (4 indicators)	A proxy of human capital, measured by tertiary education enrollment (World Development Indicators)	Human capital is an important contributor to the absorptive capacity of external investment (Borensztein et al. 1998). Tertiary education is particularly considered

Table 7 (continued)

Components of readiness measure	Indicators	Rationale
		significant in building up adaptive capacities, more than primary and secondary educations (Tol and Yohe 2007).
	A proxy of social inequality, measured by the share of the country's poorest people in national income or consumption (Millennium Development Goals)	Incremental adaptation investment is more likely safeguard the interest of the most marginalized, who are also the more disadvantaged group when confronting with the adverse effect of climate change (Tol et al. 2004). Therefore, the use of adaptation investment is likely to generate more benefit in society with higher degree of equity.
	A proxy of innovation capacity, measured by patent registration (World Development Indicators)	A society with more innovation capacity is likely to use adaptation investment efficiently, because research and technology are necessary to define adaptation solutions (Smit and Skinner 2002).
	A proxy of information and communication technology (ICT), measured by ICT access and usage (International Telecommunication Union)	ICT infrastructure guarantees the fast delivery of information needed for actions. A society with more convenient access to and more extensive use of ICT infrastructures makes the use of adaptation investment more efficient, as it enables knowledge integration for key ingredients of adaptive capacity (Pant and Heeks 2012).

Appendix 3. Correlation of the proposed control variables

Table 8 Correlation matrix of the proposed control variables for the CFU model

CFU model	No. of disaster occurrence (excluded)	Climate Risk Index (retained)	GDP (excluded)	Population (retained)	GNI per capita (retained)
No. of disaster occurrence (excluded)	1				
Climate Risk Index (retained)	−0.3942 (0.0000)	1			
GDP (excluded)	0.8124 (0.0000)	−0.1794 (0.0607)	1		
Population (retained)	0.8213 (0.0000)	−0.2155 (0.0238)	0.8431 (0.000-0)	1	
GNI per capita (retained)	0.1561 (0.1083)	−0.0090 (0.9263)	0.2027 (0.034-5)	0.0370 (0.7026)	1

For data sources, see Table 1

Table 9 Correlation matrix of the proposed control variables for the AII model

AII model	No. of disaster occurrence (excluded)	Climate Risk Index (retained)	GDP (excluded)	Population (retained)	GNI per capita (retained)
No. of disaster occurrence (excluded)	1				
Climate Risk Index (retained)	−0.3875 (0.0000)	1			
GDP (excluded)	0.8561 (0.0000)	−0.2249 (0.0182)	1		
Population (retained)	0.6171 (0.0000)	−0.2417 (0.0106)	0.3422 (0.000-2)	1	
GNI per capita (retained)	0.2056 (0.0345)	0.1732 (0.0717)	0.2880 (0.002-2)	−0.0476 (0.6195)	1

For data sources, see Table 1

Appendix 4. ND-GAIN's Vulnerability-Readiness Matrix

Figure 2 visualizes vulnerability and readiness scores in the Vulnerability-Readiness Matrix (VRM) that illustrates a country's position in a two-dimensional plane. The median vulnerability and readiness scores from 1995 to 2014 delineate four quadrants on the VRM. To explore the spread of countries across the parameter space of the index, we plot all countries on the VRM from the most recent data publication for the year 2014. The VRM shows that countries with higher readiness tend to have lower vulnerability and vice versa.

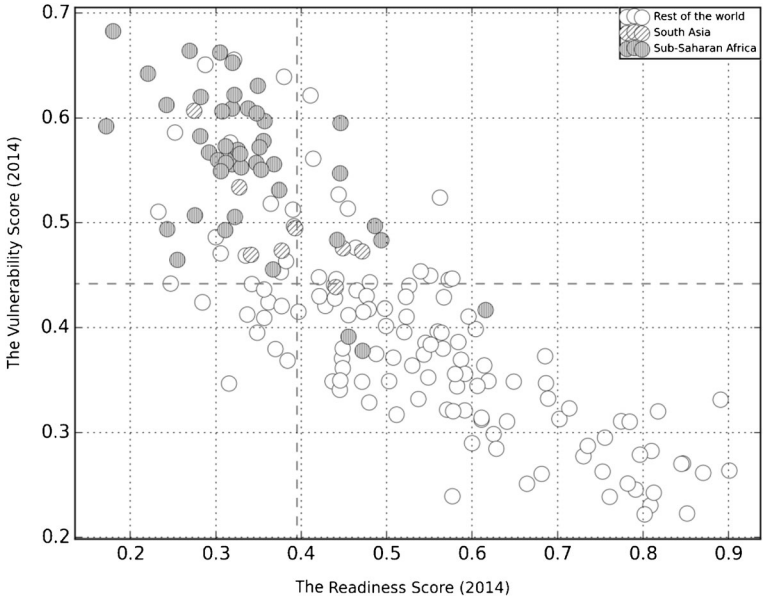

Fig. 2 Vulnerability-Readiness Matrix, based on 2014 data. Each *dot* represents one country. The median vulnerability and readiness scores from 1995 to 2014 delineate four quadrants on the matrix. Countries occupy one of the four quadrants of the matrix according to their vulnerability and readiness scores. The countries are grouped according to the geographic locations: (1) Sub-Saharan Africa; (2) South Asia; and (3) rest of the World (data source: Notre Dame Global Adaptation Initiative)

References

Aakre S, Rübbelke DTG (2010) Adaptation to climate change in the European union: efficiency versus equity considerations. Environ Policy Gov 20:159–179. doi:10.1002/eet.538

Addison T, Heshmati A (2003) The new global determinants of FDI flows to developing countries: the importance of ICT and democratization. WIDER Discussion Papers // World Institute for Development Economics (UNU-WIDER)

Adger WN (2006) Vulnerability. Glob Environ Change 16:268–281. doi:10.1016/j.gloenvcha.2006.02.006

Adger WN, Huq S, Brown K et al (2003) Adaptation to climate change in the developing world. Prog Dev Stud 3:179–195. doi:10.1191/1464993403ps060oa

Adger WN, Brooks N, Bentham G, et al. (2004) New indicators of vulnerability and adaptive capacity. Tyndall Cent Clim Change, UK

AF (2014) Readiness Program for Adaptation Finance. http://www.adaptation-fund.org/wp-content/uploads/2015/01/AF%20Readiness%20Flyer%2008.20.2014%20updated.pdf. Accessed 14 Nov 2016

Agrawala S (2004) Adaptation, development assistance and planning: challenges and opportunities. IDS Bull 35:50–54. doi:10.1111/j.1759-5436.2004.tb00134.x

Allison EH, Perry AL, Badjeck M-C et al (2009) Vulnerability of national economies to the impacts of climate change on fisheries. Fish 10:173–196. doi:10.1111/j.1467-2979.2008.00310.x

Aversano-Dearborn M, Beiglböck S, Binot R, et al. (2011) Regional challenges in the perspective of 2020—phase 2: deepening and broadening the analysis. Enropean Commission, Directorate General for Regional Policy, EC, Brussels, Belgium

Balica SF, Wright NG, Meulen F (2012) A flood vulnerability index for coastal cities and its use in assessing climate change impacts. Nat Hazards 64:73–105. doi:10.1007/s11069-012-0234-1

Barr R, Fankhauser S, Hamilton K (2010) Adaptation investments: a resource allocation framework. Mitig Adapt Strateg Glob Change 15:843–858. doi:10.1007/s11027-010-9242-1

Berrang-Ford L, Ford JD, Paterson J (2011) Are we adapting to climate change? Glob Environ Change 21:25–33. doi:10.1016/j.gloenvcha.2010.09.012

Berrang-Ford L, Ford JD, Lesnikowski A et al (2014) What drives national adaptation? A global assessment. Clim Chang 124:441–450. doi:10.1007/s10584-014-1078-3

Bird NM, Glennie J (2011) Going beyond aid effectiveness to guide the delivery of climate finance. ODI Background Note, ODI, London

Blömstrom M, Kokko A (2003) The economics of foreign direct investment incentives. National Bureau of Economic Research

Borensztein E, De Gregorio J, Lee J-W (1998) How does foreign direct investment affect economic growth?1. J Int Econ 45:115–135. doi:10.1016/S0022-1996(97)00033-0

Brenkert AL, Malone EL (2005) Modeling vulnerability and resilience to climate change: a case study of India and Indian states. Clim Chang 72:57–102. doi:10.1007/s10584-005-5930-3

Brooks N, Adger WN (2005) Assessing and enhancing adaptive capacity. In: Lim B, Spanger-Siegfried E, Burton I et al (eds) Adaptation policy frameworks for climate change. Cambridge University Press, Cambridge, UK

Brooks N, Neil Adger W, Mick Kelly P (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob Environ Change 15:151–163. doi:10.1016/j.gloenvcha.2004.12.006

Buchanan BG, Le QV, Rishi M (2012) Foreign direct investment and institutional quality: some empirical evidence. Int Rev Financ Anal 21:81–89. doi:10.1016/j.irfa.2011.10.001

Butt TA, McCarl BA, Angerer J et al (2005) The economic and food security implications of climate change in Mali. Clim Chang 68:355–378. doi:10.1007/s10584-005-6014-0

Chen C, Noble I, Hellmann J, et al. (2015) University of Notre Dame Global Adaptation Index Country Index Technical Report. http://index.nd-gain.org:8080/documents/nd-gain_technical_document_2015.pdf. Accessed 11 Oct 2016

CIF (2015) PPCR Programming Phase 1: Lessons on Enhancing Readiness for Climate Resilient Development, CIF Secretariat, Washington, DC, US

Cinner JE, McClanahan TR, Graham NAJ et al (2012) Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. Glob Environ Change 22:12–20. doi:10.1016/j.gloenvcha.2011.09.018

Climate Funds Update Notes and methodology. http://www.climatefundsupdate.org/about/data-figures-notes. Accessed 13 Oct 2016

COP13 (2007) Bali Action Plan, UN FCCC Secretariat, Bonn, Germany

COP21 (2015) Adoption of the Paris Agreement, UN FCCC Secretariat, Bonn, Germany

Cruce TL (2009) Adaptation planning—what U.S. states and localities are doing. Pew Center on Global Climate Change, Washington, DC, US

Cutter SL, Boruff BJ, Shirley WL (2012) Social vulnerability to environmental hazards. In: Cutter SL (ed) Hazards vulnerability and environmental justice. 1st edn. Routledge, New York

DARA, Climate Vulnerable Forum (2012) Climate vulnerability monitor: a guide to the cold calculus of a hot planet. DARA, Madrid

Deressa TT, Hassan RM, Ringler C et al (2009) Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob Environ Change 19:248–255. doi:10.1016/j.gloenvcha.2009.01.002

Djankov S, McLiesh C, Klein MU et al (eds) (2004) Doing business in 2004: understanding regulation. World Bank, Washington, DC, US

Donner SD, Kandlikar M, Webber S (2016) Measuring and tracking the flow of climate change adaptation aid to the developing world. Environ Res Lett 11:54006. doi:10.1088/1748-9326/11/5/054006

Economics of Climate Adaptation Working Group (2009) Shaping climate-resilient development—a framework for decision-making. Climate Works Foundation; Global Environmental Facility; European Commission; McKinsey&Company; The Rockfeller Foundation; Standard Chartered Bank; SwissRe

Engle NL (2011) Adaptive capacity and its assessment. Glob Environ Change 21:647–656. doi:10.1016/j.gloenvcha.2011.01.019

ESPON Climate (2011) Climate change and territorial effects on regions and local economies. ESPON & IRPUD, TU Dortmund

European Commission (2006) Investment readiness. European Commission, Directorate-general for enterprise and industry, EC, Brussels, Belgium

Farole T, Winkler DE (2012) Foreign firm characteristics, absorptive capacity and the institutional framework: the role of mediating factors for FDI spillovers in low- and middle-income countries. Social Science Research Network, Rochester, NY

Feenstra JF, Burton I, Smith JB, Tol RS (1998) Handbook on methods for climate change impact assessment and adaptation strategies. UNEP, Nairobi, Kenya

Flamini V, Schumacher ML, McDonald MCA (2009) The determinants of commercial bank profitability in Sub-Saharan Africa. International Monetary Fund, Washington, DC, US

Füssel H-M (2005) Vulnerability in climate change research: a comprehensive conceptual framework. University of California International and Area Studies Breslauer Symposium Paper 6, Berkeley

GCF (2015) Readiness Programme Overview, Green Climate Change Fund Secretariat, Songdo, S. Korea

Girma S (2005) Absorptive capacity and productivity spillovers from FDI: a threshold regression analysis*. Oxf Bull Econ Stat 67:281–306. doi:10.1111/j.1468-0084.2005.00120.x

GIZ (2013) Ready for climate finance: GIZ's approach to making climate finance work. GIZ GmbH, Berlin

Grasso M (2010) An ethical approach to climate adaptation finance. Glob Environ Change 20:74–81. doi:10.1016/j.gloenvcha.2009.10.006

Hajat S, Vardoulakis S, Heaviside C, Eggen B (2014) Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. J Epidemiol Community Health 68:641–648. doi:10.1136/jech-2013-202449

Hallegatte S, Bangalore M, Vogt-Schilb A (2016) Assessing socioeconomic resilience to floods in 90 countries. Policy Research working paper; no. WPS 7663. Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/387821467309551281/Assessing-socioeconomic-resilience-to-floods-in-90-countries

Halpern BS, Longo C, Hardy D et al (2012) An index to assess the health and benefits of the global ocean. Nature 488:615–620. doi:10.1038/nature11397

Hay JE (2012) Disaster risk reduction & climate change adaptation in the Pacific: an institutional and policy analysis. UNISDR, UNDP, Suva, Fiji

Heritage Foundation (2016) Methodology | 2016 index of economic freedom book. In: 2016 Index Econ. Freedom—Methodol. http://www.heritage.org/index/book/methodology . Accessed 1 Jun 2016

IDA (2007) IDA's performance-based allocation system: simplification of the formula and other outstanding issues. The World Bank

Inderberg TH, Eriksen SH, O'Brien KL, Sygna L (eds) (2015) Climate change adaptation and development: transforming paradigms and practices. Routledge, Taylor & Francis Group, Abingdon, Oxon; New York, NY

International Telecommunication Union (2013) Measuring the Information Society Report. Geneva Switzerland

IPCC (2012) IPCC, 2012: Summary for policymakers. In: Managing the risks of extreme events and disasters to advance climate change adaptation: [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp 1–19

IPCC (2014) Annex II: Glossary [Agard, J., E.L.F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olsson, B. Osman-Elasha, M. Pelling, M.J. Prather, M.G. Rivera-Ferre, O.C. Ruppel, A. Sallenger, K.R. Smith, A.L. St Clair, K.J. Mach, M.D. Mastrandrea, and T.E. Bilir (eds.)]. In: Barros VR, Field CB, Dokken DJ, et al. (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects.

Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 1757–1776

IPCC WGI SPM (2013) IPCC, 2013: summary for policymakers. In: Stocker TF, Qin D, Plattner G-K, et al. (eds) Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IPCC WGII SPM (2014) IPCC, 2014: Summary for policymakers. In: Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (ed) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Kates RW, Travis WR, Wilbanks TJ (2012) Transformational adaptation when incremental adaptations to climate change are insufficient. Proc Natl Acad Sci 109:7156–7161. doi:10.1073/pnas.1115521109

Kaufmann D, Kraay A, Mastruzzi M (2011) The worldwide governance indicators: methodology and analytical issues. Hague J Rule Law 3:220–246. doi:10.1017/S1876404511200046

Kelly PM, Adger WN (2000) Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Clim Chang 47:325–352. doi:10.1023/A:1005627828199

Klapper LF, Love I (2010) The impact of business environment reforms on new firm registration. Social Science Research Network, Rochester, NY

Klein R (2010) Linking adaptation and development finance: a policy dilemma not addressed in Copenhagen. Clim Dev 2:203–206

Kreft S, Eckstein D, Dorsch L, et al. (2015) Global Climate Risk Index 2016 who suffers most from extreme weather events? Weather-related loss events in 2014 and 1995 to 2014

Krishnamurthy PK, Lewis K, Choularton RJ (2014) A methodological framework for rapidly assessing the impacts of climate risk on national-level food security through a vulnerability index. Glob Environ Change 25:121–132. doi:10.1016/j.gloenvcha.2013.11.004

Lesk C, Rowhani P, Ramankutty N (2016) Influence of extreme weather disasters on global crop production. Nature 529:84–87. doi:10.1038/nature16467

Lesnikowski AC, Ford JD, Berrang-Ford L et al (2013) National-level factors affecting planned, public adaptation to health impacts of climate change. Glob Environ Change 23:1153–1163. doi:10.1016/j.gloenvcha.2013.04.008

Lesnikowski AC, Ford JD, Berrang-Ford L et al (2015) How are we adapting to climate change? A global assessment. Mitig Adapt Strateg Glob Change 20:277–293. doi:10.1007/s11027-013-9491-x

Lesnikowski A, Ford J, Biesbroek R et al (2016) National-level progress on adaptation. Nat Clim Chang 6:261–264. doi:10.1038/nclimate2863

Lindgren E, Andersson Y, Suk JE et al (2012) Monitoring EU emerging infectious disease risk due to climate change. Science 336:418–419. doi:10.1126/science.1215735

Lindner M, Maroschek M, Netherer S et al (2010) Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For Ecol Manag 259:698–709. doi:10.1016/j.foreco.2009.09.023

Lobell DB, Burke MB (2010) On the use of statistical models to predict crop yield responses to climate change. Agric For Meteorol 150:1443–1452. doi:10.1016/j.agrformet.2010.07.008

Margulis S, Dubeux C, Marcovitch J (2011) The economics of climate change in Brazil: costs and opportunities. São Paulo: FEA/USP, 2011

Mendelsohn R (2000) Efficient adaptation to climate change. Clim Chang 45:583–600. doi:10.1023/A:1005507810350

Mercer J (2010) Disaster risk reduction or climate change adaptation: are we reinventing the wheel? J Int Dev 22:247–264. doi:10.1002/jid.1677

Metzger MJ (2005) European vulnerability to global change: a spatially explicit quantitative assessment. Dissertation, Wageningen University

Meza FJ, Silva D, Vigil H (2008) Climate change impacts on irrigated maize in Mediterranean climates: evaluation of double cropping as an emerging adaptation alternative. Agric Syst 98:21–30. doi:10.1016/j.agsy.2008.03.005

Mina W (2007) The location determinants of FDI in the GCC countries. J Multinatl Financ Manag 17:336–348. doi:10.1016/j.mulfin.2007.02.002

Mostafa M, Rahman MF, Huq S (2016) Climate adaptation funding: getting the money to those who need it. Bull At Sci 72:396–401. doi:10.1080/00963402.2016.1240480

Mutekwa VT (2009) Climate change impacts and adaptation in the agricultural sector: the case of smallholder farmers in Zimbabwe. J Sustain Dev Afr 11:237–256

Naylor RL, Battisti DS, Vimont DJ et al (2007) Assessing risks of climate variability and climate change for Indonesian rice agriculture. Proc Natl Acad Sci 104:7752–7757. doi:10.1073/pnas.0701825104

ND-GAIN (2015) Matrix | ND-GAIN Index. http://index.gain.org/matrix. Accessed 5 Nov 2016

Nogués-Bravo D, Araújo MB, Errea MP, Martínez-Rica JP (2007) Exposure of global mountain systems to climate warming during the 21st century. Glob Environ Change 17:420–428. doi:10.1016/j.gloenvcha.2006.11.007

O'Brien K, Leichenko R, Kelkar U et al (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Change 14:303–313. doi:10.1016/j.gloenvcha.2004.01.001

OECD (2015) Climate change risks and adaptation linking policy and economics: linking policy and economics. OECD, Paris, France

Oregon Department of Transportation (2014) Climate Change Vulnerability Assessment and Adaptation Options Study. Available at: http://www.oregon.gov/odot/td/climatechange/docs/adaptationpilot.pdf

Paavola J, Adger WN (2006) Fair adaptation to climate change. Ecol Econ 56:594–609. doi:10.1016/j.ecolecon.2005.03.015

Pant LP, Heeks R (2012) ICT-enabled development of capacity for climate change adaptation. ICTs Clim Change Dev Themes Strateg Actions Univ Manch UK Int Dev Res Cent IDRC Can 116–132

Persson A, Remling E (2014) Equity and efficiency in adaptation finance: initial experiences of the Adaptation Fund. Clim Policy 14:488–506. doi:10.1080/14693062.2013.879514

Piao S, Ciais P, Huang Y et al (2010) The impacts of climate change on water resources and agriculture in China. Nature 467:43–51. doi:10.1038/nature09364

Preston BL, Stafford-Smith M, Climate Adaptation Flagship (2009) Framing vulnerability and adaptive capacity assessment: discussion paper. CSIRO Climate Adaptation National Research Flagship, St Lucia, Qld

Remling E, Persson Å (2015) Who is adaptation for? Vulnerability and adaptation benefits in proposals approved by the UNFCCC Adaptation Fund. Clim Dev 7:16–34. doi:10.1080/17565529.2014.886992

Schewe J, Heinke J, Gerten D et al (2014) Multimodel assessment of water scarcity under climate change. Proc Natl Acad Sci 111:3245–3250. doi:10.1073/pnas.1222460110

Schipper L (2007) Climate change adaptation and development: exploring the linkages. Tyndall Cent Clim Change

Smit B, Skinner MW (2002) Adaptation options in agriculture to climate change: a typology. Mitig Adapt Strateg Glob Change 7:85–114. doi:10.1023/A:1015862228270

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Change 16:282–292. doi:10.1016/j.gloenvcha.2006.03.008

Smit B, Burton I, Klein RJT, Wandel J (2000) An anatomy of adaptation to climate change and variability. Clim Chang 45:223–251. doi:10.1023/A:1005661622966

Stockholm Environment Institute (2008) Financing adaptation to climate change

Suk JE, Ebi KL, Vose D et al (2014) Indicators for tracking European vulnerabilities to the risks of infectious disease transmission due to climate change. Int J Environ Res Public Health 11:2218–2235. doi:10.3390/ijerph110202218

Sullivan C, Meigh J (2005) Targeting attention on local vulnerabilities using an integrated index approach: the example of the climate vulnerability index. Water Sci Technol 51:69–78

Surminski S (2013) Private-sector adaptation to climate risk. Nat Clim Chang 3:943–945. doi:10.1038/nclimate2040

Thomalla F, Downing T, Spanger-Siegfried E et al (2006) Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. Disasters 30:39–48. doi:10.1111/j.1467-9523.2006.00305.x

Thow A, De Blois M (2008) Climate change and human vulnerability: mapping emerging trends and risk hotspots for humanitarian actors. Geneva, Switzerland

Tol RSJ, Yohe GW (2007) The weakest link hypothesis for adaptive capacity: an empirical test. Glob Environ Change 17:218–227. doi:10.1016/j.gloenvcha.2006.08.001

Tol RSJ, Downing TE, Kuik OJ, Smith JB (2004) Distributional aspects of climate change impacts. Glob Environ Change 14:259–272. doi:10.1016/j.gloenvcha.2004.04.007

Tubiello FN, Rosenzweig C (2008) Developing climate change impact metrics for agriculture. The Integrated Assessment Journal 8 (1):165–184

Twomlow S, Mugabe FT, Mwale M et al (2008) Building adaptive capacity to cope with increasing vulnerability due to climatic change in Africa—a new approach. Phys Chem Earth Parts ABC 33:780–787. doi:10.1016/j.pce.2008.06.048

UN FCCC (2004) United Nations Framework Convention on Climate Change: The first ten years. UN FCCC, Bonn, Germany

UNEP - Climate change—adaptation—economics of climate change adaptation. http://www.unep.org/climatechange/adaptation/EconomicsandFinance/EconomicsofclimatechangeadaptationtabId/29586/Default.aspx. Accessed 10 Aug 2016

United Nations (2015) Transforming our world: the 2030 Agenda for Sustainable Development. Available at: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

Vandeweerd V, Glemarec Y, Billett S (2012) Readiness for climate finance: a framework for understanding what it means to be ready to use climate finance UNDP, New York

Vörösmarty CJ, Green P, Salisbury J, Lammers RB (2000) Global water resources: vulnerability from climate change and population growth. Science 289:284–288. doi:10.1126/science.289.5477.284

Wheeler D (2011) Quantifying vulnerability to climate change: implications for adaptation assistance. Social Science Research Network, Rochester, NY

Wheeler T, Von Braun J (2013) Climate change impacts on global food security. Science 341:508–513. doi:10.1126/science.1239402

WHO (2014) WHO | Climate change 2014: impacts, adaptation, and vulnerability. In: WHO. http://www.who.int/globalchange/environment/climatechange-2014-report/en/. Accessed 31 May 2016

World Bank (2016) Country and Lending Groups | Data. http://data.worldbank.org/about/country-and-lending-groups. Accessed 1 Jun 2016

Yohe G, Tol RSJ (2002) Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity. Glob Environ Change 12:25–40. doi:10.1016/S0959-3780(01)00026-7

Yohe GW, Malone E, Brenkert A, et al. (2006) Global distributions of vulnerability to climate change. The Integrated Assessment Journal 6(3):35–44

Young BE, Byers E, Hammerson G, Frances A, Oliver L, Treher A (2015) Guidelines for using the NatureServe Climate Change Vulnerability Index Release 3.0. Arlington, VA: NatureServe

Zahra SA, George G (2002) Absorptive capacity: a review, reconceptualization, and extension. Acad Manag Rev 27:185–203. doi:10.2307/4134351