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Foreign finance, economic growth and CO_2 emissions Nexus in OECD countries

Faris Alshubiri
Dhofar University, Salalah, Oman, and
Mohamed Elheddad
Hull University Business School, Hull, UK

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Abstract

Purpose – This study aims to examine the relationship between foreign finance, economic growth and CO_2 to investigate if the environmental Kuznets curve (EKC) exists as an empirical evidence in 32 selected Organization for Economic Co-operation and Development (OECD) countries.

Design/methodology/approach – This study used quantitative analysis to test two main hypotheses: *H1* is the U-shape relationship between foreign finance and environment, and *H2* is the N-shaped association between economic growth and environment. In doing so, this study used panel data techniques. The panel set contained 32 countries over the period from 1990 to 2015, with 27 observations for each country. This study applied a panel OLS estimator via fixed-effects control to address heterogeneity and mitigate endogeneity. Generalized method of moments (GMM) with fixed effects-instrumental variables (FE-IV) and diagnostic tests were also used.

Findings – The results showed that foreign finance and environmental quality have an inverted U-shaped association. The three proxies' foreign investment, foreign assets and remittance in the first stages contribute significantly to CO_2 emissions, but after the threshold point is reached, these proxies become "environmentally friendly" by their contribution to reducing CO_2 emissions. Also, a non-linear relationship denotes that foreign investment in OECD countries enhances the importance, as a proxy of foreign finance has greater environmental quality than foreign assets. Additionally, empirical results show that remittances received is linked to the highest polluted levels until a threshold point is reached, at which point it then helps reduce CO_2 emissions. The GMM and FE-IV results provide robust evidence on inverse U-shaped relationship, while the N-shaped relationship explains that economic growth produces more CO_2 emissions at the first phase of growth, but the quadratic term confirms this effect is negative after a specific level of GDP is reached. Then, this economic growth makes the environment deteriorate. These results are robust even after controlling for the omitted variable issue. The IV-FE results indicate an N-shaped relationship in the OECD countries.

Practical implications – Most studies have used different economic indicators as proxies to show the effects of these indicators on the environment, but they are flawed and outdated regarding the large social challenges facing contemporary, socio-financial economic systems. To overcome these disadvantages, the social, institutional and environmental aspects of economic development should also be considered. Hence, this study aims to explain this issue as a relationship with several proxies in regard to environmental, foreign finance and economic aspects.

Originality/value – This paper uses updated data sets for analyzing the relationship between foreign finance and economic growth as a new proxy for pollution. Also, this study simulates the financial and environmental future to show their effect on investments in different OECD countries. While this study

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enhances the literature by establishing an innovative control during analysis, this will increase to add value. This study is among the few studies that empirically investigate the non-linear relationship between finance and environmental degradation.

Keywords Economic growth, CO_2 emissions, OECD countries, Foreign finance

Paper type Research paper

1. Introduction

The economic growth activities of different countries affect global CO_2 emissions. This has led to several countries aiming to obtain clean energy and therefore shift environmental policy focus toward greenhouse gas emissions (GHGs), which has caused a rapid transformation on economy (Pegkas, 2015). This has become evident through several countries' adoption of sustainable development and has instigated a change in strategy regarding the management of environmental resources (Paramati *et al.*, 2017). Economic factors that can help achieve a clean environment include reducing capital costs and increasing foreign assets (Al Mamun *et al.*, 2018).

Climate financing refers to resources that promote resilient development by allocating finances to create conditions that support the adaptation and mitigation of a negative climate impact and promote scientific research using modern climate financing technologies (Fernandes and Paunov, 2012). Sustainable financing continues to attract significant global attention in regard to funding environmental and infrastructural initiatives effective financing (Maddison and Rehdanz, 2008).

The magnitude of the climate change challenge is important to the international community and requires reflection on pre-industrial production levels and consumption processes to encourage countries to adopt policies that stimulate investment and address possible climate change (Galeotti *et al.*, 2009).

In this context, governments in different countries need to provide companies substantial support to adapt of environment changes, especially in developing countries, which are directly affected by the accumulation of buried gases in the atmosphere (Salahuddin *et al.*, 2018). Hence, the magnitude of the fiscal challenge to achieve this transformation makes it difficult for climate financing to absorb resources, which is also dependent on the resources available to each country (Akbostanci *et al.*, 2009). Specifically, developing countries lack the necessary financial resources, institutional and policy systems and skills to effectively finance climate initiatives (Pao and Tsai, 2011).

Climate change is a highly inconsistent development issue with unbalanced effects according to a country's income development pathways (Hao and Liu, 2015). These effects are unbalanced because it is likely that climate change damage will be more severe in lower-income countries (Ozturk and Acaravci, 2010).

Therefore, high-income countries have aimed to aid developing countries in reducing negative climatechange impacts via the establishment of the Green Climate Fund and financing technology (Maddison and Rehdanz, 2008). However, the slow growth of climate financing in these countries has created a challenge regarding scientific financial targets (Zhang and Zhou, 2016).

The threat of climate change raises difficult questions regarding how to implement them and what infrastructure will be developed (Alfaro *et al.*, 2004). Many countries have begun to propose policies that stabilize current emission levels to achieve a clean environment, which includes the costs of mitigation and adaptation (Wang, 2009).

These countries also strategize on how to share the burden of funding based on country pollution levels that have caused current damage (Lee, 2009). Acharyya (2009) sought to establish these standards by determining a country's capacity to financially contribute based on their gross domestic product (GDP) and emission levels.

All multi-lateral development banks (MDBs) announced ambitious, multi-year targets in late 2015 involving the rapid expansion of climate financing activities to support the adaptation and mitigation in developing countries and emerging economies, adding to the momentum set by the Paris Agreement (Koçak and Şarkgüneşi, 2018). Moreover, MDBs are expanding in several relevant activities such as institutional capacities, technical support and providing access to the financial system (Pao and Tsai, 2010). The Paris Agreement indicates that progress beyond previous effort regarding the flow of finance is needed to support a path for adapting to climate change and reducing GHGs (Ozturk and Acaravci, 2010).

In 2015, MDBs established more than US$25bn to climate financing, funding more than US$131bn total in climate work since 2011. MDBs have implemented many common methodologies for developing the climate budget finance, enhancing transparency to achieve a global financial development flow (WDI, 1990/2016).

In the same year, common principles were developed in regard to mitigation and adaptation activities through the International Finance Club for Development (IFC), which involved establishing a set of guidelines for co-financing climate flow in which more than US$55bn dollars was invested (WDI, 1990/2016).

Some of the most important roles of MDBs include reducing the costs and risks associated with climate financing investments and building the institutional capacity of operations (Nguyen and Amin, 2002). The resources of MDBs manage only part of the global climate finance landscape, contributing only fractionally to low-carbon initiatives and flexible infrastructure (Dogan and Turkekul, 2016).

MDBs continue to work with public sources to provide risk-sharing measures specifically designed to stimulate private financing (Nguyen and Amin, 2002). In addition, they also strengthen the capacities of their client countries to enable the establishment of specific climate change projects and provide effective access to resources (Acharyya, 2009). Climate model funding studies are still scarce; however, Soytas and Sari (2009) suggest that the global carbon tax is the most important element for countries to fund.

The impact of financial development is still unclear. There are a variety of existing arguments regarding his predictions and explanations of its possible effects. One school of thought suggests that financial development leads to an increase in energy consumption by increasing economic growth (Sadorsky, 2010; Shahbaz and Lean, 2012). A high degree of financial development leads to higher economic growth, which requires more energy consumption. However, a second school of thought believes that financial development helps reduce CO_2 emissions through the energy efficiency effect. Financial development aids listed companies in enhancing energy efficiency, significantly cutting carbon emissions. Also, certain financial services, such as green bonds, are considered environmentally friendly.

There is a third-party belief that financial development has a non-linear relationship with energy consumption. In previous literature, such as Mahalik *et al.* (2017) argued that energy demand rises as the development of the financial sector increases (i.e. credit allocation to firms). After a threshold level of financial development is reached, the financial sector encourages adopting an energy-efficient technology for their businesses, which as a result reduces the intensity of energy use. This explains the relationship between financial development and energy consumption is an inverted U-shape. Therefore, it can be hypothesized that financial development has a concave relationship with energy consumption.

The study's contribution includes questioning burden sharing, whether it will have an impact on global climate change and how all countries will receive these policies. The study also addresses the research gap that links economic, foreign financial and environmental variables to assess growth in a clean environment, despite technological developments and heavy industries that create environmental emissions that affect the welfare of society.

This study aims to development policies regarding finance climate change. Additionally, it contributes to the enhancement of current knowledge regarding this factor. It is the first study to diagnose a country's foreign, financial and economic growth in regard to CO_2 emissions within a sample of 32 selected Organization for Economic Co-operation and Development (OECD) countries. In the course of the study, several panel data methods, such as the GMM and IV-FE approaches, were performed.

This study gives enhanced understanding of the hypotheses, Figures 1 and 2 show the possible correlation between foreign finance measurements and CO_2 emissions. A careful observation of these correlations shows that the foreign finance–environmental quality relationship in OECD economies is driven by non-linear relationships. In other words, foreign finance increases pollution at the first stage, and it then helps reduce CO_2 generating the inverted U-shape association. These figures help investigate the possible non-linear relationship between foreign finance and pollution in OECD countries.

This study found that foreign finance and environmental quality have a concave relationship. Furthermore, the foreign investments of three proxies, foreign assets and remittance in the first stages contribute significantly to CO_2 emissions; however, after the threshold point was reached, these proxies became "environmentally friendly" via their contribution to reducing CO_2 emissions. Also, this paper found that there is a non-linear relationship illustrating that foreign investment (as a proxy of foreign finance) in OECD countries enhances the importance of environmental quality because it more significantly improves the environmental quality than foreign assets. Additionally, empirical results show that remittances received variable is the most polluted until a certain level, upon which it then helps reduce CO_2 emissions. This study also found that there is an N-shaped

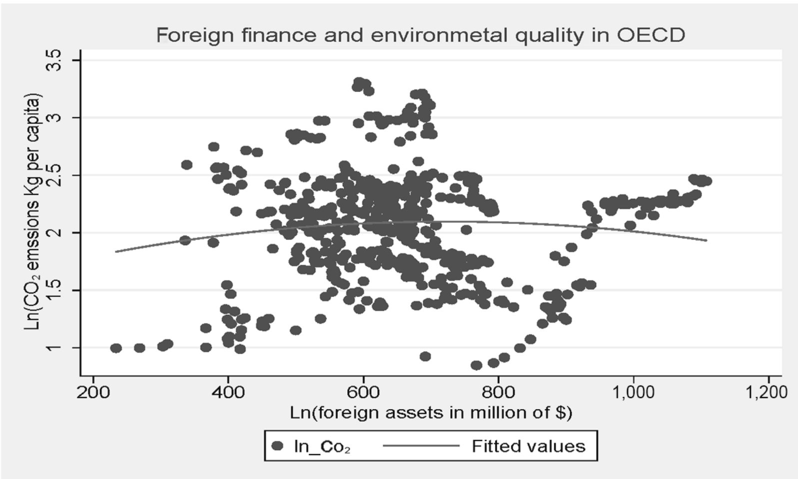

Figure 1.
Plots of foreign assets and CO_2 emissions relationship

Source: (STATA.15 output)

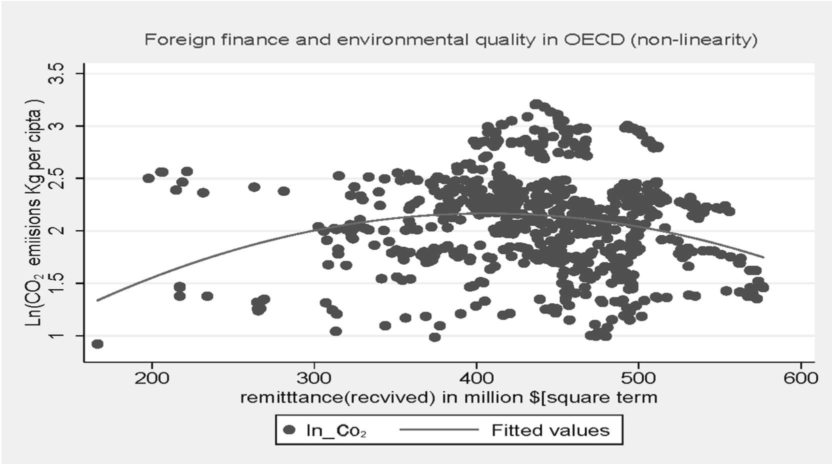

Figure 2.
Plots of remittance and CO_2 emissions relationship

Source: (STATA.15 output)

relationship that explains that economic growth produces more CO_2 emissions at the first stage of economic growth than beyond the first threshold level, economic growth improves the quality of environment. After that, there is a second threshold level; this economic growth makes the environment deteriorate. Overall, the results of this study were robust even after controlling for the omitted variable.

The structure of this paper, following the introduction, is organized as follows: Section 2 reviews foreign finance, economic growth and CO_2 by explaining the environmental Kuznets curve (EKC) theory and then presents previous studies. Section 3 discusses the methodology, data and equations used, while Section 4 presents the empirical results and discussion. Finally, Section 5 provides the conclusions and policy implications.

2. Foreign finance, economic growth and CO_2: a literature review

This section reviews previous papers on the relationship between economic growth, foreign direct investment (FDI) and CO_2 emissions. For clarity, this literature review is comprised of two segments relating to two different categories within the literature: the economic growth-CO_2 emissions nexus and the nexus between FDI and CO_2 emissions. The following sections discuss both nexus by drawing on existing and relevant evidence.

2.1 Economic growth-CO_2 emissions relationship

Global warming in regard to climate change has become an important issue, as CO_2 is one of the leading concerns of most countries (Fernandes and Paunov, 2012). This issue has only grown significantly in recent years due to human-produced activities involving oil, gas and other chemicals, which are the main energy and electricity resources in various industrial, service and transport sectors and are directly related to growth (Galeotti *et al.*, 2009). Therefore, the EKC developed by Kuznets (1955) highlights the inequality of income relationship, which assumes that countries begin to develop economic inequality that increases to a certain degree, and after that, the disparity begins to decline after reaching average income represented by an inverted U-shape.

Since the pioneering work of Grossman and Krueger (1955), the EKC has attracted significant attention and garnered several empirical applications. The EKC hypothesis suggests that economic growth at an initial stage requires a high demand for raw materials and natural resources, which leads to more CO_2 emissions and harmful waste. Therefore, in the early phase of economic development, pollution and economic growth grow parallel. After a certain amount of time, modern techniques and technology are introduced in developed economies; consequently, industrial waste begins to diminish, mitigating environmental decay.

Salahuddin *et al.* (2018) noted that improving economic growth causes environmental problems because increased production levels increase environmental pollution. However, Acharyya (2009) mentions that a hypothesis regarding economic development and environmental issues is more complex. On the other hand, Hao and Liu (2015) argue that economic growth can improve environmental output through countries' continued clean production. Overall, these theories confirm that it is essential to understand the dynamic environment and what its effect is on the economic situation and environmental degradation (Ozturk and Acaravci, 2010).

The EKC theory plays a vital role in several environmental pollutants, but the most important source regarding this concept was developed by Lau *et al.* (2014) in reference to CO_2. Carbon dioxide (CO_2) is considered a major source of environmental issues and comprises the largest portion of GHGs. Many previous studies explain the financial and economic activities that affect CO_2 and confirm CO_2's effect on pollution from a global perspective (Koçak and Şarkgüneşi, 2018).

The model is formulated as a U-shaped relationship between variables of economic growth or foreign financial indicators and pollution measured by CO_2 emissions.This model is a dynamic process of change regarding the growth and increased income of an economy over time as the level of CO_2 emissions, at the first step, reaches its peak before beginning to decline and reaching the point of income required (Sadorsky, 2010). The relationship begins with the link between economic growth and increase in CO_2 emissions, and then, these emissions become exhausted when the economy reaches the stage of economic growth (Pao and Tsai, 2010).

The EKC model represents structural changes in the environmental economy with economic growth (Lau *et al.*, 2014). Economic growth can be linked to continuous structural transformations in different industrial sectors of society and is based on the content of change, which varies from one period to the next depending on the economy over time. The most common stage is the transfer of growth from agriculture to industry, which is then followed by a spread of these systems into industrial services (Ren *et al.*, 2014). Environmental degradation becomes concentrated due to the noticeable change in the economic structure resulting from the transformation of production elements from rural to urban areas and from the agricultural sector to industries that are based on intensive production and consumption. This occurs after a certain point of decline, which is a result of the entry of technology and heavy industries that contribute positively to the development of economic and financial sectors of society (Dogan and Turkekul, 2016).

The increased use of natural resources causes increased pollutant emissions, with a phase of economic development beginning to evolve (Pao and Tsai, 2010). When countries begin to increase their industrial activity, it becomes increasingly important to educate individuals about the environment, which can lead to higher environmental spending, increased technology efficiency and an increased demand for an efficient environment (Ren *et al.*, 2014).

When the income of individuals increases, heavy industrial production becomes phased out in favor of more technologically advanced and service-intensive production. This development is a positive obstacle to the increase of pollution (Zhang and Zhou, 2016). The effects of a high-tech and productive economy contribute to low pollution, high demand for a clean climate, increased political concern and increased levels of prosperity in the community (Galeotti *et al.*, 2009). Moreover, any increase in pollution levels is due to increased production, which requires increased production inputs and an increased use of natural resources (Alfaro *et al.*, 2004).

Technology is an important factor in economic growth if it is used effectively to benefit the environment. The basic economic theory explains that countries should work at a competitive advanatageto achieve a low price for products by investing in both effective technology and developing economic and financial sectors, which will ultimately affect the environment and pollution levels (Zhang and Zhou, 2016). This occurs when the heavy industry in economy moves toward a more intensive economy, which can be explained by the increased need for research and development that increases the per capita GDP without increasing the levels of pollution (Koçak and Şarkgüneşi, 2018).

Hao and Liu (2015) and Alfaro *et al.* (2004) argue that dirty production (manufacturing industry) is represented in developing countries with high levels of pollution, while green production is represented in developed countries with low levels of pollution and results in international trade.

2.2 Foreign finance-CO_2 emissions relationship

Foreign economies assessing energy levels through foreign capital inflow is necessary to help emerging countries finance clean energy projects (Paramati *et al.*, 2017). This view is based on external factors such as the capital flow, transfer of technology and economic knowledge that leads to the reduction of CO_2 emissions.

The global development of financial markets increases the consistency of information on the deployment of renewable energy via external financing (Lee, 2013). Alfaro *et al.* (2004) stated that the quality of the environment enhances a country's financial development. It is essential that foreign energies contribute to the flow of foreign capital, as this will promote sustainable development, create clean energy and reduce environmental degradation.

Much of the previous literature is related to the current study in one or more ways. For example, financing climate is one component of green financing, which is funded through governments. This refers to the transfer of financial flow to projects regarding the environment and society by reducing the percentage of pollution.

Sectors such as banking, insurance and investing stimulate business in society. Countries are also working to adopt a green financing policy by avoiding certain project risks to ensure that the implementation of these projects will not harm the environment. Lee (2009) argued that the interaction of FDI activities can cause carbon emissions. Furthermore, Pao and Tsai (2011) showed BRIC countries that are FDI can also cause carbon emissions. Lau *et al.* (2014) found that the co-integration of FDI variables can increase CO_2 emissions, while Ren *et al.* (2014) applied the generalized method of moment (GMM) estimation and found that FDI leads the industry sector with CO_2 emissions.

Görg and Strobl (2005) explained that foreign investment is affected by the flow of technology in all countries. However, the countries that benefit from technology in a positive manner reflected on the positive environment regarding the ecosystems and macroeconomic nature of these countries. Eskeland and Harrison (2003) argued that multinational companies in emerging countries do not tend to pollute the environment, while Dasgupta *et al.* (2000) explained that environmental compliance in emerging countries is important for analyzing environmental impact and policy-making. The results indicated that environmental management has a significant impact on compliance rules. Cole *et al.* (2008) indicated that foreign training benefits the environment by reducing the use of fuel (especially in foreign companies) and environmental pollution. Albornoz *et al.* (2009) indicated that foreign companies implement environmental regulations and operate under formal and informal channels. Moreover, Doytch and Uctum (2016) found that the type of investment inflow affects the industrial and non-financial sectors and may be negatively impacted. Overall, the unequal distribution of income in developing countries can harm the environment.

Akbostanci *et al.* (2009) indicated that there is a long-term relationship between income increase and environmental activities, which ensures that when income rises, it will affect production and cause a certain percentage of pollution, while Galeotti *et al.* (2009) argued that the EKC model does not always provide indicators of CO_2 in society. In another study by Maddison and Rehdanz (2008), a strong, causal relationship between GDP per capita and environment was found. Behera and Dash (2017) applied fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) estimators to show that there is a positive effect of the FDI on CO_2 emissions.

Similarly, Koçak and Şarkgüneşi (2018) explained that technology may contribute to energy saving during productive activities and thus contribute to a positive relationship between foreign investment and the environment. For instance, Hao and Liu (2015) argued that FDI reduces CO_2 emissions through the application of the GMM procedure. Similarly, Zhang and Zhou (2016) proposed that reducing CO_2 emissions with FDI conserves energy via the adoption of an energy-efficient technology.

Nguyen and Amin (2002) analyzed foreign investment demand for energy and a clean environment and found a positive relationship between these factors, which promotes consumer energy and stimulates production in a country. In another study by Mielnik and Goldemberg (2002), there was evidence that FDI increases CO_2 emissions. In a recent study by Salahuddin *et al.* (2018), it was found that foreign activities increase CO_2 emissions.

Lee (2009) suggested an adverse effect between economic growth and the activities of energy consumption, which varies according to the financial economic development of countries in both the short and long term. Behera and Dash (2017) highlighted the fact that there is a strong correlation between economic growth and foreign investment in most developed and emerging countries. Furthermore, Hao and Liu (2015) found that there is a long- and short-term impact of foreign investments on the outputs of economic development. Sadorsky (2010) found that foreign investment is significantly correlated with demand for energy in more than 22 emerging countries, arguing that the obtainment of large loans will cause an increase in CO_2 emissions by developing the infrastructure of financial development.

Ren *et al.* (2014) explained that countries in industrial zones encourage many foreign investors to begin investing, and because there is still little knowledge on how to use resources more efficiently, an increase CO_2 will occur. On the other hand, Shahbaz *et al.* (2013) focused on the private sector and found that financial development does not have a large effect on CO_2 emissions.

This shows that several studies have examined the relationship between FDI or financial development on environmental degradation, but few studies have examined the impact of foreign finance (i.e. FDI), remittances and foreign assets as three indicators of CO_2 emission levels to conserve clean energy and achieve a sustainable environment.

3. Methodology

3.1 Empirical model and data

This empirical paper aimed to examine the association between foreign finance and economic growth on CO_2 emissions in selected OECD economies. To achieve this aim, this paper applied panel data techniques. The panel set contained 32 out of 36 OECD countries, exempting four countries: New Zealand, Poland, the Slovak Republic and Slovenia. The study examined these countries from 1990 to 2015 and ensured the obtainment of 27 observations for each country. The proposed model for this study was based on the theoretical framework developed by Doytch and Uctum (2016):

$$CO_2 = \left(FF_{i,t},\, FF^2_{i,t},\, GDP_{i,t},\, GDP^2_{i,t},\, GDP^3_{i,t}\right) \tag{1}$$

Where CO_2 is carbon dioxide emission per capita, FF is various foreign finance proxies for country i in time t and GDP is gross domestic product per capita as a proxy for economic growth. All variables were measured by a natural logarithm to attain reliable results. Also, this logarithm form helped interpret the coefficients, as all coefficients could be expressed as elasticities, which provided a clear interpretation of the results. Therefore, the proposed model was:

$$\begin{aligned} \text{In\_}CO_2 \;&=\; \beta 0 + \beta 1\text{In\_}FF_{i,t} + \beta 2\text{In\_}FF^2_{i,t} + \beta 3\text{In\_}GDP_{i,t} + \beta 4\text{In\_}GDP^2_{i,t} \\ &\quad + \beta 5\text{In\_}GDP^3_{i,t} + \upsilon_i + \mathrm{e}_{i,t} \end{aligned} \tag{2}$$

where betas are estimated as parameters based on their signs. There were two main hypotheses that were the focus of this study: EKC foreign finance (FF)-CO_2 emissions and EKC economic growth-CO_2 emissions.

The EKC can take several shapes according to parameters related to income (Alvare *et al.* (2016, 2018).

- $\beta 3 > 0$ and $\beta 4 = \beta 5 = 0$; in this situation, the relationship is monotonic, increasing as environmental degradation rises along with economic growth;
- $\beta 3 < 0$ and $\beta 4 = \beta 5 = 0$; this means that there is a monotonic negative association between environmental degradation and economic growth;
- $\beta 3 > 0$, $\beta 4 < 0$ and $\beta 5 = 0$; this gives the traditional, inverse U-shaped EKC;
- $\beta 3 < 0$, $\beta 4 > 0$ and $\beta 5 = 0$; this indicates a U-shaped relationship; and
- If $\beta 3 < 0$, $\beta 4 > 0$ and $\beta 5$; this case shows an inverse N-shaped relationship between environmental degradation and income.

In regard to financial development, the inverted U-shape between foreign financial development and environmental quality is present when $\beta 1 > 0$ and $\beta 2 < 0$ (Shahbaz *et al.*, 2013).

This study used a variety of different proxies as foreign financial indicators to increase the robustness of the results. Following the previous studies, FDI (Acharyya, 2009; Lau *et al.*, 2014; Blanco *et al.*, 2013), forging assets (Shahbaz *et al.*, 2018), remittances (Akçay and Demirtaş, 2015) were used in this study. Economic growth measured by real GDP per capita was constant at 2010 prices. The definitions of variables and the data sources are reported in Table I. All variables were extracted from the World Bank (World Development Indicators,

Table I.
FF, economic growth and CO_2 emissions: FE model

Dependent variables: Ln(CO_2 per capita) Independent variables	(1) FDI	(2) Foreign assets	(3) Remittance paid	(4) Remittance received
Ln (GDP per capita)	47.65*** (8.135)	−1.847 (6.579)	21.39*** (6.231)	39.30*** (5.666)
Ln (GDP per capita^2)	−4.781*** (0.822)	0.301 (0.660)	−2.120*** (0.628)	−3.906*** (0.571)
Ln (GDP per capita^3)	0.159*** (0.0276)	−0.0139 (0.0220)	0.0700*** (0.0210)	0.129*** (0.0191)
Ln (FDI)	*0.109*** (0.0476)			
FDI^2	*−0.00222*** (0.00109)			
Ln (foreign assets)		*0.0726*** (0.0369)		
Ln (foreign assets^2)		*−0.00149** (0.000784)		
Ln (remittance(paid))			*0.130**** (0.0382)	
Ln (remittance(paid)^2)			*−0.00387**** (0.00104)	
Ln (remittance(received))				*0.366**** (0.0432)
Ln (remittance(received)^2)				*−0.00993**** (0.00111)
Constant	−155.9*** (26.75)	3.495 (21.73)	−70.73*** (20.56)	−132.6*** (18.68)
Observations	336	528	712	738
R^2	0.151	0.063	0.045	0.174
Number of ID	26	31	32	32
Country fixed	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Hausman test for Fixed Effects	6.78 (0.07)	3.01 (0.039)	7.38 (0.06)	2.63 (0.0451)
F-test	10.87 (0.00)	6.65 (0.00)	6.35 (0.00)	29.53 (0.00)

Notes: STATA version 15 output; standard errors in parentheses *at $p < 0.10$; **at $p < 0.05$; ***at $p < 0.01$

1990/2016). Not all data were available for all countries after 2015, so the study period was limited from 1990 to 2015, which is considered a limitation of this study.

3.2 Estimation strategies

This paper began estimations of our model by applying a panel OLS estimator (fixed-effects (FE) and random-effects (RE) models). These methods are commonly used in panel data analysis. The fixed effects model is appropriate due to its ability to control for unobserved country effects (i.e. heterogeneity issues). To choose whether the FE or RE model was most appropriate, a Hausman test was conducted for the FE model. The null hypothesis of this test was that the RE model is more efficient. Overall, the FE model was preferable because it controls for unobserved country-specific effects and mitigates the problem of multicollinearity.

However, panel OLS estimators can suffer from an endogeneity problem due to correlations between the dependent variable(s) and the error term. Therefore, the GMM approach was applied to overcome this issue, a method proposed by Arellano and Bond (1991) and developed by Roodman (2009). To test the robustness of the results; this study also applied the instrumental variables (IV) – FE estimator.

4. Results and discussions

4.1 Empirical results: fixed-effects model

This section empirically attempts to test the hypotheses regarding the U-shape relationship between FF and pollution and the N-shape growth-pollution thesis.

4.1.1 The foreign finance-CO_2 emissions association: the inverted U-shape relationship hypothesis. Beginning with *H1*, which was related to the FF–pollution relationship, Table I reports the findings on 32 OECD countries based on the FE model estimator. Column 1 of this table shows the estimates for the first proxy of FF, which is a net, FDI inflow. The result indicates an inverted U- shaped association between net FDI and CO_2 emissions, which means that foreign investment in the first stages contributes significantly to CO_2 emissions, but, after reaching the threshold point, these investments become more "environmentally friendly" via their contribution to reducing CO_2 emissions.

These empirical findings are consistent with Nguyen and Amin (2002) who showed that foreign capital creates additional funds to promote technology development and support the environment. Conversely, Salahuddin *et al.* (2018) found that there is no significant statistical relationship between financial development and clean energy use, as the nature of investments is not clean and technology is not used in applications that provide advantages for reducing costs. The financial technology used did not adequately reflect the development of the financial system.

In Table I, Column 2, the model was re-estimated by using the second proxy of foreign financial development, which refers to foreign assets. The inverted U-shape hypothesis is confirmed again. It should be noted that foreign assets contribute less to CO_2 emission levels in OECD (coefficient 0.07) compared with FDI (0.109) based on the linear relationship. While the non-linearity denotes that foreign investment in OECD countries enhances the importance of environmental quality over foreign assets (seethe FDI-squared term coefficient in the results). Similarly, Zhang and Zhou (2016) mentioned that CO_2 emission can be improved through FDI inflow, which induces clean energy consumption.

Additionally, FF was proxies using remittance variables, personal remittances received and personal remittances paid. These two variables comprise the personal transfers and compensation of an employee. The findings in Table I Columns 3 and 4 show that remittances (paid and received) have an inverse U-shaped association with pollution, while the findings also show that remittances received are the most polluted FF in OECD countries until a certain level, at which point it then helps reduce CO_2 emission. These results once again validate the inverted U-shaped association, indicating that foreign remittances received are used to improve clean energy use and thus work to develop the financial system. Lee (2009) confirmed this result by alluding to the causal relationship related to clean energy consumption.

The concave relationship between finance and energy consumption can be explained by the fact that, initially, energy demand rises because of financial development sector increase, but after a threshold level of financial development is reached, the financial sector encourages adopting energy-efficient technology for their businesses, which as a result reduces the intensity of energy use. This indicates that the relationship between financial development and energy consumption is an inverted U-shape (Mahalik *et al.*, 2017). This is significantly true in regard to FDI and financial assets.

This is because remittance boosts energy consumption. Increasing migrant remittances improves the standard of living of the recipient households and increases their income, thus increasing the demand for energy. This indirect effect of external financing may increase productive investments, which can be defined as investments that improve household income in the future in ways that are generated by non-remittance (Akçay and Demirtaş, 2015). Because of this significant impact, governments of different countries impose certain regulations in different industries to mitigate energy consumption.

4.1.2 Economic growth-CO_2 emissions association: the N-shape relationship hypothesis. Next, the validity of the N-shaped relationship between CO_2 emissions and economic growth was examined. In Table I, it can be seen that pollution increases when economic growth increases up to a certain point, at which point CO_2 emissions then decreased. Again, the greater of economic activities, the greater will be the increase in pollution in OECD economies. This indicates that economic growth begins first with improving the quality of the environment and has a positive relationship until it reaches a certain level of income, with the relationship becoming negative once more, which canpotentially be explained by the increase in energy efficiency.

The increase in CO_2 can be explained by the active activities of foreign investments operating in these countries, allowing technology to flow to less prosperous countries. Thus, technological developments may exceed the industrial activities in society, leading to the pollution of the local environment due to a heavy industry or a negative impact of GDP on CO_2. The N-shape can be interpreted through low per capita income initially, leading to an initial increase in pollution but then an eventual decrease over time with a per capita income increase. At some point, however, income emissions may begin to rise again.

4.2 Generalized method of moments and instrumental variable estimations

One potential concern could involve the preferred FF variables that are endogenous and the expected reverse causality between these proxies and CO_2 emissions. Therefore, this issue was mitigated by applying the common estimator, which is the GMM that uses IVs (IV-FE) estimators to ensure robustness. The GMM and IV-FE results are reported in Table II. These results provide robust evidence regarding the inverse U-shaped relationship between FF proxies and the environmental quality measure based on CO_2 emissions per capita. Also, these results provide significant evidence regarding the N-shape of economic growth and pollution.

4.2.1 The foreign finance-CO_2 emissions association: the inverted U-shape relationship hypothesis. In recent years, foreign investments and assets have been considered an important economic driving force behind many countries, with energy flow, economic

Table II.
FF, economic growth and CO_2 emissions: GMM and IV-FE result

Dependent variable: Ln (CO_2 per capita)	(1) IV (FDI)	(2) GMM (FDI)	(3) IV (foreign assets)	(4) GMM (foreign assets)	(5) IV remittance (paid)	(6) GMM remittance (paid)	(7) IV remittance (received)	(8) GMM remittance (received)
Ln(FDI)	*0.163***(0.0650)	*0.0673* (0.0530)						
Ln(FDI^2)	*−0.00331*** (0.00144)	*−0.00125* (0.00124)						
Ln(GDP per capita)	39.12*** (8.066)	10.94 (15.73)	1.452 (7.033)	−13.64 (20.29)	22.82*** (6.491)	27.38 (20.05)	44.89*** (6.075)	45.30*** (15.43)
Ln (GDP per capita^2)	−3.881*** (0.818)	−0.908 (1.598)	−0.0362 (0.707)	1.433 (2.039)	−2.273*** (0.655)	−2.807 (2.025)	−4.466*** (0.613)	−4.549*** (1.567)
Ln (GDP per capita^3)	0.127*** (0.0275)	0.0238 (0.0540)	−0.00246 (0.0236)	−0.0495 (0.0680)	0.0754*** (0.0220)	0.0961 (0.0679)	0.148*** (0.0205)	0.152*** (0.0529)
Ln (foreign assets)			*0.0963*** (0.0452)	*−0.0450* (0.143)				
Ln (foreign assets^2)			*−0.00192*** (0.000952)	*0.000669* (0.00294)				
Ln (remittance (paid))					*0.168**** (0.0399)	*0.411*** (0.178)		
Ln (remittance (paid)^2)					*−0.00490**** (0.00108)	*−0.0121*** (0.00490)		
Ln (remittance (received))							*0.328**** (0.0480)	*0.337*** (0.141)
Ln (remittance (received) ^{2})							*−0.00893**** (0.00122)	*−0.0107**** (0.00389)
Constant	−130.0*** (26.39)		−7.500 (23.22)		−75.56*** (21.38)		−150.7*** (20.01)	
Observations	243	190	475	422	684	651	708	675
Number of ID	23	20	31	31	32	31	32	32
R^2	0.17		0.05		0.0556		0.1644	
AR (1))		−0.71 (0.49)		−0.76 (0.445)		−1.21 (0.225)		−1.48 (0.140)
AR (2)		−0.17 (0.86)		−0.88 (0.376)		−0.14 (0.885)		−0.831 (0.408)
Hansen test		15.13 (1.00)		24.57 (1.00)		30.09 (1.00)		30.90 (1.00)
Wald test	178.7 (0.000)		162.4 (0.000)		267.1 (0.000)		326.4 (0.000)	

Notes: STATA version 15 output; standard errors in parentheses *at $p < 0.10$; **at $p < 0.05$; ***at $p < 0.01$

growth and environmental pollution having also been cited. Some studies have tested the causal relationship between foreign assets and the quality of the environment. Sadorsky (2010) explained that most CO_2 emissions were found to be due to heavy industries, while Blanco *et al.* (2013) argued that the best investment options lie in developing countries due to the decline in strict environmental policies.

Mielnik and Goldemberg (2002) pointed out that foreign investment is not a source of pollution because it uses advanced technology within a sophisticated infrastructure. Furthermore, it is evident in Table II that foreign investments contribute significantly to pollution when they increase by 10 per cent, with approximately 11 per cent on average (GMM coefficient 0.163 + IV coefficients 0.067/2); however, investment after a certain level (turning point) helps promote green investments, which can consequently help reduce CO_2 emissions.

Also, the results confirm that remittances are the most important factor in regard to CO_2 emissions. The coefficient of remittances was 0.33 and 0.34. This refers to the fact that CO_2 emissions increase by 3.3 and 8.4 per cent when remittances rise by 10 per cent.

4.2.2 The economic growth-CO_2 emissions association: the N-shape relationship hypothesis. Again, the results regarding CO_2 emissions and economic growth confirm the N-shape relationship. The findings also prove the existence of the N-shaped relationship between GDP per capita and environmental degradation. Examining the results of the OLS estimation in Table II, it is evident that economic growth produces higher CO_2 emission levels at the beginning of economic growth, but the quadratic term confirms this effect becomes negative after a certain level of GDP is reached. Then, this economic growth causes the environment to deteriorate. Thus, the result is robust even after controlling for the omitted variable issue. Overall, the IV-FE results indicate an N-shaped relationship in the OECD countries.

This result is consistent with findings by Shahbaz *et al.* (2013), who argued for the inverted N-shape, and Lee (2009), who argued other economic factors influence economic growth and contribute to an increased demand for clean consumption practices. Other studies, such as those of Soytas and Sari (2009) and Chandran and Tang (2013), show that clean consumption reduces CO_2 emissions in the in ASEAN-5 economies. These results are consistent with the policy effects on most countries regarding the creation of foreign assets. Additionally, Pao and Tsai (2010) explained that economic growth levels and activities of energy consumption have an effect on environmental degradation in most countries, while Akbostanci *et al.* (2009) tested the EKC theory and found a long-term relationship between CO_2 and income.

National policies and the international investment structure attract investments through OECD countries for economic growth. Addressing the challenges of host countries in regard to building a broad, transparent base to enable the political environment of investment and institutional building, OECD countries contribute to development by facilitatinga way for developing countries to access technology and benefit from public projects and encouraging non-OECD member countries to adhere to international frameworks based on investment rules.One of the potential disadvantages of OECD countries is the deterioration of the balance between payment and profits, as foreign investment works to compensate revenues. Therefore, OECD countries should improve the domestic investment environment where the adverse environment can impact investment turmoil due to the presence of heavy, extractive industries accelerating in the least developed countries. Competition in national markets is affected by foreign investment; therefore, the host economy is often unable to benefit from technology or the knowledge transferred through foreign investment.

Policies play an important role in establishing FDI that will be influenced by many facors, such as the expected profitability of individual projects and the ease of handling subsidiaries and the strategies on which the foreign investment and comprehensive quality of the environment of the host country are based. However, there are some factors that determine expected profitability based on the size of the local market and geographical location.

The OECD has a primary responsibility to act as headquarters for sharing member experiences regarding tools used for cooperation in foreign investment through long-term investment policy references and recommendations from governments with different views.

The success of such an approach depends on the mechanisms for coordinating the use of resources for capacity-enhancing and technical assistance. Moreover, the assistance of a country does not only depend on another singular country but rather on collective, international determination to build an inter-related investment capacity. CO_2 emission levels is one of the contemporary issues of concern for OECD countries; climate change can have significant social consequences that affect human well-being and increase the risk of sudden changes in climate and ecosystems. Approximately 70 per cent of the CO_2 emissions stem from the energy extracted due to an increase in global energy demand, and emissions are expected to increase due to an increased demand for cars, especially in developing countries. Historically, OECD countries are responsible for increasing emissions, and economic growth is one of the main reasons for this increase. Technological advances and structural transformations are expected to improve energy usage in the countries. OECD countries have also made progress in the development of national climate adaptation strategies and have been encouraging the assessment and management of climate risks in relevant sectors. Increased private sector involvement is also essential in regard to the integration of climate change adaptation in development cooperation. The increase in real GDP growth rate, low inflation rates, low unemployment rates and improved external account growth are four major objectives of not only OECD countries but all countries in the world in regard to the creation of economic policies.

4.3 Diagnostic tests

This section reports and discusses the findings in Tables I and II by testing certain widely used diagnostic tests to check whether or not the results are consistent and unbiased. We perform the Hausman test to select the appropriate model for FE and RE. The results showed that the Hausman test strongly rejected the null hypothesis regarding the RE model being appropriate (Table I).

Additionally, focus was placed on the Sargan test statistics, which examine the correlation between IVs and endogenous variables (Arellano and Bond, 1991).

The GMM results confirm that the instruments are exogenous and not over-identified. The null hypothesis regarding this fact is therefore rejected in Table II (Hansen test statstics). Another important test was the Arellano and Bond test for autocorrelation. This test checks for autocorrelation among residuals. Based on Arellano and Bond autocorrelation AR (1) and AR (2) statistics, the null hypothesis was rejected.

5. Conclusion and policy implication

Environmental degradation plays a vital role in challenges faced by the economies of several countries. The consequences of the heavy pollution that has persisted for several years have been influential in short- and long-term perspectives as well as at local and global levels. From a local perspective, pollution affects local ecosystems directly, and thus, when ecosystem dynamics are changed, the balance of living organisms disintegrates and affects all parts of the society. This situation can affect a country's economic and financial systems, as the environmental system affects the ability to attract investments and assets, foreign remittances and all foreign financial work, in the sense that the degree of control affected by the level of environmental situation available.

Economic growth and FF have become important factors and are dominated by environment, in which it has been noted that increasing production and foreign investment correlated with increasing pollution in the environment. Some hypotheses have found that the association between economic and FF indicators with environmental degradation is difficult to explain. There are also several assumptions regarding the fact that economic and financial growth improves the environment, and therefore, it is important to understand this interconnected relationship between the environment and economic system.

This study aimed to examine the relationship between FF, economic growth and CO_2 emissions to investigate if the EKC exists as empirical evidence among the 32 selected OECD countries. This study used quantitative tests for the hypotheses and applied panel data techniques. The panel set contained 32 countries during the period from 1990 to 2015 and ensured 27 observations for each country. This study applied a panel OLS estimator through an FE model and solved the endogeneity issue using the GMM, IV-FE estimators and diagnostic tests. The empirical findings provide two interesting results: the FF–environmental degradation relationship is shaped like an inverted U and the relationship between economic growth and CO_2 emissions is N-shaped.

For FF–CO2 emission, the inverse U-shaped association is consistent with the finding of Shahbaz *et al.* (2013). There are two possible explanations behind this behavior: first, it is related to the transition from the manufacturing industry (i.e. the dirty sector) to the service sector. This process increases CO_2 emissions at the initial stage, but then helps to reduce pollution (Shahbaz *et al.*, 2013). Also, OECD governments provide loans and financial aid to green projects.

The second is related to environmental regulations. The OECD countries impose strict rules on multinational firms. At the first stage, they locate operations to save environmental costs, which usually are industries are pollution-intensive industries (i.e. pollution havens) (Blanco *et al.*, 2013), but due to environmental constraints, multinational firms face environmental regulation, especially in OECD countries. This then leads to the improvement of efficient energy use (Mielnik and Goldemberg, 2002).

For the economic growth–CO_2 emissions relationship, the results are in line with the findings of Churchill *et al.* (2018) and Allard *et al.* (2018). The curve was initially an inverted U-shape, but after a certain point, emissions once again rose and the relationship became U-shaped.

The results of this study analyze the methods used by economic and financial decision-makers in each country by describing the strengths and weaknesses of their performances in the financial and social economy and their design of economic policy that helps attract investments and increase economic growth. This study supports the policies of OECD countries for creating economic and financial conditions conducive to environmental systems. Furthermore, it calls for the adoption of green environmental practices, which require the continuous consideration of the created policies.This study calls for further research to search for analytical economic and financial models explaining the beahaviour of economic system to ensure the establishment of economic policies that are compatible with the environment, social effects and economic and financial growth through their application in a wideselection of ideologically different countries. The study recommends that future research is needed to consider social and political variables that can add value to FF and economic grwoth and impact the environment situation.

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Further reading

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Appendix 1

Table AI.
Variable definitions and sources

Variable	Definition	Source
CO_2 emissions (metric tons per capita)	CO_2 emissions are generated by the burning of fossil fuels, the consumption of solid fuels, liquids and gas and the activities of the cement industry	World Development Indicators
FDI, net inflows (constant US$)	FDI refers to cash flows or investment stocks that flow into the state, contribute to the building of the state's economy and achieve a degree of control over economic growth	World Development Indicators
Net foreign assets (constant US$)	Foreign assets represent foreign liabilities, which are invested in the country from external sources and are held by the government's monetary authorities	World Development Indicators
Personal remittances paid (constant US$)	Including all current transfers made in cash or in kind made or received by family's resident in the state or to non-resident households	World Development Indicators
Personal remittances received (constant US $)	Including all current transfers made in cash or in kind by or received by family's resident in the state or to non-resident families	World Development Indicators
GDP per capita	GDP per capita is the gross domestic product (GDP) divided by mid-year population. GDP represents the total value added of all producers residing in the country's economy as well as any product taxes minus any subsidies not included in the value of the product	World Development Indicators

Appendix 2. Sample (32 countries)

Included: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the UK and the USA.

Excluded: New Zealand, Poland, the Slovak Republic and Slovenia.

Appendix 3

Variable	Observations	Mean	SD	Minimum	Maximum
CO_2 emissions per capita	793	9.066	4.463	2.328	27.431
FDI net inflows	795	5.89e + 09	3.47e + 10	−2.58e + 11	2.11e + 11
Foreign assets	815	6.92e + 12	3.45e + 13	−3.05e + 13	3.99e + 14
GDP per capita (constant 2010)	848	35680.52	20920.29	5132.953	112000
Remittance paid	789	4.41e + 09	8.32e + 09	181000	6.32e + 10
Remittance Received	812	2.98e + 09	4.46e + 09	400000	2.87e + 10

Source: STATA version 15 output

Table AII.
Descriptive statistics

Appendix 4

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) CO_2 per capita	1.000											
(2) FDI	0.088	1.000										
(3) foreign asset	0.041	0.115	1.000									
(4) GDP capita	0.385	0.060	−0.200	1.000								
(5) remittance paid	0.389	0.280	0.043	0.214	1.000							
(6) remittance received	−0.167	0.074	0.079	−0.143	0.349	1.000						
(7) GDP^2	0.337	0.079	−0.222	0.941	0.217	−0.152	1.000					
(8) GDP^3	0.343	0.077	−0.223	0.952	0.218	−0.151	0.999	1.000				
(9) FDI^2	0.201	0.716	0.137	0.104	0.448	0.321	0.117	0.115	1.000			
(10) Remittance $paid^2$	0.371	0.222	0.149	0.279	0.630	0.439	0.263	0.266	0.655	1.000		
(11) Remittance $received^2$	−0.015	0.125	0.142	−0.066	0.402	0.707	−0.088	−0.085	0.518	0.746	1.000	
(12) foreign $asset^2$	−0.031	0.135	0.589	−0.087	0.129	0.237	−0.116	−0.115	0.241	0.294	0.240	1.000

Source: STATA version 15 output

Table AIII.
Correlation matrix

Corresponding author
Faris Alshubiri can be contacted at: falshubiri@du.edu.om

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Upgrading destruction?

How do climate-related and geophysical natural disasters impact sectoral FDI

Nadia Doytch
Koppelman School of Business, Brooklyn College, CUNY, New York, New York, USA; PhD Program in Economics, Graduate Center, CUNY, New York, New York, USA and Ateneo de Manila University, School of Government, Manila, The Philippines

Abstract

Purpose – The authors investigate natural disasters' impact on manufacturing and services foreign direct investment (FDI), both, in contemporaneous and time-lag contexts. Manufacturing and services FDI account for different types of technology transfers, respectively, through tangible physical assets and intangible knowledge assets. This paper aims to hypothesize that natural disasters that have pronounced physical impact, have different effect on different sectoral FDI.

Design/methodology/approach – The authors merge a data set from emergency events database, which covers natural disasters occurrences with a sector-level data on FDI for 69 countries for the period 1980-2011, distinguishing between four different kinds of natural disasters such as meteorological, climate, hydrological and geophysical, as well as between different geographical regions.

Findings – Controlling for commonly accepted determinants of FDI, such as output growth, quality of institutions and natural resource abundance, the authors find that manufacturing FDI is negatively affected immediately after the disaster and positively in the longer run- a finding that is in unison with the "creative destruction" growth theory. Services FDI, on the other hand, do not show such pattern. Meteorological disasters have no effect on services FDI and climate and hydrological disasters have long-lasting negative effects. For both, manufacturing and services FDI, geophysical disasters have a positive impact on FDI in the long run.

Research limitations/implications – The study is limited to 69 countries for the period 1980-2011.

Practical implications – FDI bears tangible and intangible knowledge assets and provides means of financing, even in countries with under-developed banking systems and stock markets. FDI is impacted by climate change, manifested by intensifying and increase of frequency of natural disasters.

Social implications – Natural disasters destroy infrastructure and displace people. The rebuilding of infrastructure and intangible capital present an opportunity for upgrading.

JEL classification – Q54, F21

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Originality/value – This is the first study that analyzes the impact of natural disasters on sector-level FDI in a multicounty and regional context.

Keywords Natural disasters, Climate-related natural disasters, Geographical regions, Geophysical natural disasters, Manufacturing and services FDI, Sectoral FDI, FDI inflows

Paper type Research paper

1. Introduction

Foreign direct investment (FDI) is a main source of financing for developing countries. FDI bears tangible and intangible knowledge assets and provides means of financing, even in countries with under-developed banking systems and stock markets. Like most of the macroeconomy, FDI is impacted by climate change. One of the manifestations of climate change is the intensifying and increase of frequency of natural disasters. The research on the economic impact of natural disasters, however, in still in its infancy. Natural disasters destroy or damage infrastructure, displace people and diminish human capital resources. However, in spite of the hypothesized negative initial impact, the long-run effects of disasters need not be negative. The replacement and rebuilding of infrastructure and intangible capital present also an opportunity for upgrading. The current study aims at exploring these links.

The theoretical foundation for the economic analysis of natural disasters resides in part with growth theory. Some of the questions discussed by the natural disaster literature concern the short-run and the long-run impacts of disasters on GDP. The hypothesis raised by many studies is that although the immediate impact of a disaster could be negative, the process of re-building the economy could lead to a recovery beyond the pre-disaster GDP levels. This hypothesis is broadly based on the endogenous growth theory of "creative destruction." By analogy with the "creative destruction" growth hypothesis, here we test for an "upgrading destruction" by hypothesizing that a natural disaster can destroy old capital assets working with outdated technologies and lead to a rebuilding using advanced technologies and practices (Skidmore and Toya, 2002; Hallegatte and Dumas, 2009; Doytch and Klein, 2018; Noy and Vu, 2010).

However, not all studies find empirical support for this capital upgrading theory. Some studies argue about a recovery to the trend. They reason that there is post-disaster rise in marginal productivity of capital, which is because of less capital available for the same number of workers. This eventually leads to converging to pre-disaster levels (Smith *et al.*, 2006; Vigdor, 2008; Belasen and Polachek , 2008, 2009; Hornbeck, 2012; Strobl, 2011; Boustan *et al.*, 2012).

In addition, some studies find that the outcome of catastrophes' impact depends on the country level of development. Crespo Cuaresma *et al.* (2008) find that risk has a negative effect on the volume of knowledge spillovers between industrialized and developing countries and that only developed countries experience capital upgrading after a natural disaster. This, according to their study, happens through international trade.

As economic resources are limited and there are competing ends for their use, disaster-spurred replacement of capital is good for growth only if there is capital upgrading. The two ways of upgrading can occur through domestic innovation and through adoption of foreign technology. For developing countries, FDI is one of the important vehicles for adoption of new technology. Moreover, post-disaster domestic investment may be constrained in ways of financing, if the financial system experiences post-disaster stress. In addition, any post-disaster fall in the value of the domestic assets would make them seem attractive to foreign investors. Therefore, it is not unreasonable to expect that FDI plays an important role in capital upgrading in disaster-prone countries and especially developing disaster-prone countries.

Although the link between natural disasters and foreign investment appears to be important for post-disaster growth, it has not been well explored. The only published studies we could find are Escaleras and Register (2011) and Anuchitworawong and Thampanishvong (2015) , with the second one performed on Thailand. As we argue below, both of them have some limitations and none of them explores sectoral differences in FDI, which may be important for disaster risk management. We seek to fill in this gap.

In the current study, we ask the question: is there a pattern that shows FDI increasing as a result of natural disasters? When we control for other commonly accepted determinants of FDI, such as the growth rate of income, quality of institutions and natural resource abundance, do we see a change in post-disaster FDI and does the disaster reaction of FDI differ in the short and the long run? Further, is there a difference between the reaction of manufacturing sector FDI inflows and services sector FDI? Arguably, the two sectoral flows transfer different kinds of technology as follows: manufacturing sector FDI-technology embodied in tangible physical assets such as equipment upgraded for advanced production processes, and services FDI-technology embodied in intangible knowledge assets, such as information technology know-how, organizational skills, marketing and distribution strategies and so on. that does not get easily destroyed by natural disasters (UNCTAD, 2004; Doytch and Uctum, 2011). The tangible/intangible aspect of the damages are also the object of the newly developed typology of disasters that claims intangible losses could be qualified as “higher-order” long-run effects of disasters (López, 2009; Noy and Du Pont IV, 2016).

The contributions of this study are multi-fold. Mainly, first, to our knowledge, this is the first study that merges the widely-used emergency events database (EM-DAT) data set on natural disasters with detailed sector-level data for FDI for 69 countries for 1980-2011[1] and applies a system generated method of moments (GMM) to deal with the endogeneity between FDI and income. This is an improvement over the methodology used in Escaleras and Register (2011) . Second, we distinguish between four kinds of catastrophic disasters as follows: meteorological, climate, hydrological and geophysical disasters while estimating both, short-run (contemporaneous) and long-run (five-year lagged) effects of natural disasters on FDI. We are also able to explore the effects of disasters within several geographical regions as follows: West Europe (a developed region); Eastern Europe and Central Asia (a region of transitional economies); South and East Asia and the Pacific (developing countries regions); and Latin America and the Caribbean (developing countries regions)[2]. Third, to disentangle the tangible/intangible aspect of capital upgrading, we consider the effects of two kinds of FDI flows manufacturing and services FDI. This is a unique feature of this study. The sectoral and industry-level differences in FDI are often ignored in the FDI determinants literature, too.

Our findings are intriguing. We find some nuances in the effects of natural disasters on manufacturing and services FDI. Manufacturing FDI shows a pattern of being negatively affected immediately after the disaster and an opportunity for post-disaster capital rebuilding in a longer term, such as five years. Services FDI does not show such pattern. Some disasters, such as meteorological, have no effect; and some, such as climate and floods, have long-lasting negative effects. For both types of FDI flows-manufacturing and services, there is one common theme: the most destructive disasters – geophysical disasters have a positive impact on FDI in the long run. This appears to be the case with manufacturing FDI to Western Europe, East Europe and Central Asia, and

Latin America and the Caribbean and the case with services FDI to West Europe and South and East Asia and the Pacific.

The rest of the paper is organized as follows. Section 1 examines a literature review on natural disaster economic impacts. Section 2 discussed some stylized facts about natural disasters and FDI inflows. Section 3 introduces the model, the data, and the methodology; Section 4 discussed the empirical findings and Section 5 concludes.

2. Literature review

As previously mentioned, the impact of natural disasters on FDI has not been well explored. Most of the existing studies investigate the effects of disasters on productivity and in that discussion, there are two streams of arguments as follows: about factors mitigating disaster preparedness and about direct disaster impact. One of the seminal papers exploring the mitigating factors is the study by Noy (2009) on macroeconomic consequences of natural disasters. Noy (2009) , whose model focuses on disaster damage and disaster deaths, rather than disaster occurrences, finds that institutions and policies play a role in the magnitude of the macroeconomic consequences of natural disasters. The author identifies that: "Countries with higher literacy rates, better institutions, higher per capita incomes, larger governments and higher degree of openness to trade appear to be better able to withstand the initial disaster shock and prevent its effects spilling deeper into the macro-economy". He also finds that less openness of the capital account, more foreign exchange reserves and higher levels of domestic credit reduce disaster vulnerability. In addition, he finds that developing countries suffer larger shocks from similar disaster magnitudes than developed countries and small economies are more vulnerable than large ones. The effects on investment and trade flows, however, are inconclusive.

One of the widely cited macro-level papers on the direct economic effects of disasters is the study by Albala-Bertrand (1993) , who finds an increase in GDP, in capital formation, and in the twin deficits, especially the trade deficit. At the same time, the author finds no change in inflation and exchange rates. Rasmussen (2004) and Tol and Leek (1999) have similar findings, all in the scope of univariate analysis. In the meantime, Skidmore and Toya (2002) is one of first studies to examine the long-run impact of disasters on growth with cross-sectional country-level data set, where they account for frequency of disasters normalized by land size. They find that climatic disasters are correlated with both, accelerated human capital accumulation and increases in total factor productivity.

Exploring further the long-run effect of disasters, Noy and Du Pont IV (2016) summarize that these depend on the severity of disasters, on the income level of the economy, as well as on the size of the geographical area impacted. Meanwhile, Cavallo *et al.* (2013) clarify that only very large disasters have a negative impact on output. However, when controlling for political change, Cavallo *et al.* (2013) find that rather than having an output effect, disasters have an impact on the political systems of impacted countries and lead to radical political changes.

The above findings lead to a recent discussion about the direct and secondary effects of natural disasters. Vu and Noy (2015) describe, the secondary effects may occur because the capital replacement pulls resources from other sectors and leads to economic restructuring. With the restructuring, the economy can reach a new steady state equilibrium. However, the issue of what constitutes long-run in this case remains open. Therefore, some of the conclusions about the impact depend on the time horizon of the analysis. Disregarding the long-run economic effects may lead to incorrect conclusions[3].

Another aspect of the effects of disasters, highlighted by Noy and Vu (2010) , is that the nature of the disaster matters for the economic impact, as the nature is related to disaster predictability. For example, some countries have high exposure to storms. In this case, storms are predictable events that call for disaster preparedness. Unlike storms, geophysical disasters, such as earthquakes, are oftentimes unpredictable and catastrophic. Vulnerability to geophysical disasters is, therefore, higher and because of that the economic impact of geophysical disasters is stronger. This is the reason why in this study, we differentiate between four different kinds of disasters as follows: meteorological, climate, hydrological and geophysical disasters.

Some recent interdisciplinary research on natural disasters uses meteorological storm models, which are embedded in stochastic economic models evaluating the impact of disasters. Hsiang and Jina (2014) evaluate the long-run economic growth impact of 6,700 cyclones during 1950-2008. The meteorological data allows for reconstruction of the wind speed characteristics of the storm and allows for precise accounting of severity of each cyclone. The authors refute the "upgrading destruction" hypothesis and find that cyclone disasters do not stimulate growth and there is no evidence that short-run losses disappear in the long-run. The authors find support of declining national incomes relative to pre-disaster trend and no recovery within 20 years. This finding does not depend on the country income level.

With respect to FDI, which is the topic of the current investigation, there are very few studies that venture into analyzing the question of natural disaster impact. In general, in the post-disaster period domestic firms could see falling value of their assets, which makes them relatively cheap and more attractive for acquisition by foreign investors. This is often considered an income effect of FDI (Levy-Yeyati *et al.*, 2007; Doytch, 2019). As a result of the income effect, FDI inflows are to increase. At the same time, disasters could impact relative rates of return to capital because of an adverse effect on the marginal productivity of capital. This could be qualified as a substitution or arbitrage effect (Levy-Yeyati *et al.*, 2007). As a result of the arbitrage effect, FDI inflows are supposed to decrease. The standard FDI determinants models account also for output growth, as a proxy for the size of the market, for natural resource endowments; for quality, human capital and for quality of institutions (Doytch and Eren, 2012).

In that light, a recent study on Thailand asks about the impact on natural disasters on FDI (Anuchitworawong and Thampanishvong, 2015). The authors hypothesize that investor perception of disaster risk is a main determinant of FDI in Thailand. Although they do not find a connection between frequency of disasters and FDI, the authors find that severity of disasters, tends to lower FDI. Escaleras and Register (2011) end up with a similar conclusion based on a panel of 94 countries for 1984-2004. They also find a negative and significant effect of disasters on inward FDI. One shortcoming of the study could be the methodology of fixed effects, which does allow for control of endogeneity of some of the right-hand-side variables. Similar are the shortcomings of the study by Kukulka (2014) about the impact of catastrophic events on FDI inflow in five developing countries with high catastrophic risk of South-Eastern Asia region, i.e. Indonesia, Malaysia, Philippines, Thailand and Vietnam with an ordinary least squares methodology. The results point out to a negative correlation between FDI disaster occurrence for Thailand and Malaysia, but not for Indonesia and the Philippines.

3. Stylized facts

Table I summarizes statistics on frequency, value damaged and population affected by different types of disasters, averaged by geographical region and by year.

On average, meteorological disasters occur most often up to 27 times a year throughout the entire sample of 67 countries. Next are climate and hydrological disasters, with

Table I. Summary statistics, disaster occurrences, damages and population affected

Occurrences	Obs	Mean	Std. dev	Min	Max	Damages (thousands of US$)	Obs	Mean	Std. dev	Min	Max
All countries											
Meteorological	5,600	0.5030357	1.569486	0	27	Meteorological	5,600	167,942.5	2,740,529	0	1.58E + 08
Climate	5,528	0.290521	1.156273	0	25	Climate	5,528	42,722.27	545,557.6	0	2.13E + 07
Hydrological	5,949	0.7100353	1.511045	0	21	Hydrological	5,948	109,387.9	1,095,939	0	4.03E + 07
Geophysical	3,710	0.2773585	0.8050123	0	11	Geophysical	3,710	191,013.4	4,216,516	0	2.10E + 08
WE											
Meteorological	630	0.495238	0.963141	0	8	Meteorological	630	146,847.4	719,086.6	0	1.20E + 07
Climate	524	0.305344	0.650261	0	4	Climate	524	79,848.94	437,270.9	0	4,500,000
Hydrological	595	0.415126	0.827214	0	6	Hydrological	595	162,534.6	1,004,051	0	1.29E + 07
Geophysical	385	0.161039	0.46215	0	3	Geophysical	385	136,360.8	1,341,718	0	2.00E + 07
EECA											
Meteorological	910	0.125275	0.416543	0	3	Meteorological	910	2,880.916	24,295.52	0	392,000
Climate	1,014	0.227811	0.648771	0	8	Climate	1,014	14,455.06	150,296	0	3,600,000
Hydrological	979	0.383044	0.876505	0	10	Hydrological	979	28,093.58	201,534.5	0	3,500,000
Geophysical	664	0.152108	0.517619	0	6	Geophysical	664	38,879.54	818,641.5	0	2.10E + 07
SEAP											
Meteorological	1,260	0.969048	1.973975	0	15	Meteorological	1,260	158,980.8	874,561.9	0	1.51E + 07
Climate	980	0.629592	2.398191	0	25	Climate	980	77,171.66	894,613.6	0	2.13E + 07
Hydrological	1,120	1.5	2.612611	0	21	Hydrological	1,119	337,693.7	2,152,985	0	4.03E + 07
Geophysical	875	0.557714	1.26556	0	11	Geophysical	875	581,540.5	8,461,533	0	2.10E + 08
LAC											
Meteorological	1,015	0.386207	0.779804	0	5	Meteorological	1,015	64,215.74	437,899.1	0	7,910,000
Climate	980	0.209184	0.486925	0	4	Climate	980	15,940.4	168,638.6	0	4,300,000
Hydrological	1,085	0.725346	1.147013	0	8	Hydrological	1,085	62,303.6	863,932	0	2.76E + 07
Geophysical	770	0.267533	0.623435	0	5	Geophysical	770	72,906.65	1,136,784	0	3.00E + 07

(*continued*)

Table I.

Affected population	Obs	Mean	Std. dev	Min	Max
All countries					
Meteorological	5,600	157,734.8	2,066,278	0	1.07E + 08
Climate	5,528	335,728.4	6,406,348	0	3.00E + 08
Hydrological	5,949	585,283.8	7,571,946	0	2.43E + 08
Geophysical	3,710	43,564.12	878,573.9	0	4.74E + 07
WE					
Meteorological	5,960	148,208.7	2,003,244	0	1.07E + 08
Climate	5,828	318,446.6	6,239,696	0	3.00E + 08
Hydrological	6,289	554,068	7,365,583	0	2.43E + 08
Geophysical	3,930	41,380.52	853,732.4	0	4.74E + 07
EECA					
Meteorological	6,120	144,334.5	1,977,021	0	1.07E + 08
Climate	6,108	303,848.5	6,095,340	0	3.00E + 08
Hydrological	6,509	535,161.5	7,240,699	0	2.43E + 08
Geophysical	4,090	39,854.1	836,884.3	0	4.74E + 07
SEAP					
Meteorological	6,320	151,522.3	1,969,002	0	1.07E + 08
Climate	6,088	359,285.9	6,744,101	0	3.00E + 08
Hydrological	6,589	562,963.4	7,247,591	0	2.43E + 08
Geophysical	4,210	38,822.64	824,898.3	0	4.74E + 07
LAC					
Meteorological	6,180	143,566.8	1,967,538	0	1.07E + 08
Climate	6,088	30,7791.1	6,106,869	0	3.00E + 08
Hydrological	6,569	532,491	7,208,058	0	2.43E + 08
Geophysical	4,150	42,709.49	837,535.2	0	4.74E + 07

respective maximum frequencies of 25 and 21 time a year on average for the entire sample (Table I , left panel). The least common are the geophysical disasters, occurring on up to 11 times year in all 67 countries studies.

The frequency, however, does not capture well the destruction of assets. The most damaging ones appear to be the geophysical disasters with a mean value loss of $191,013,400 or approximately US$200m per country per year for our sample of countries (Table I , middle panel)[4]. The second most destructive appear to me meteorological disasters (Table I , middle panel). However, the type of disasters that affect the most people are the hydrological disasters on average close to 600,000 people per country per year vs geological disasters that effect on average about 50,000 people per country per year (Table I , right panel). Of course, the average numbers are hard to interpret in a sample with heterogeneous climatic and geophysical conditions. For that reason, we look at geographical regions.

The region with the greatest frequency of disasters is SEAP: up to 15 meteorological, 25 climate, 21 floods and 11 geophysical disasters in a given country and year (Table I , left panel). The capital value destroyed by disasters in this region is also staggering: on average close to US$600m lost in geophysical disasters per country per year: more than US$300m lost in flood disasters per country per year; approximately US$150m value lost in storm disasters per country/year, and another US$80m lost in climate disasters per country/year (Table I , middle panel). There are large populations affected in disaster zones in Asia with floods heading the statistics close to 600,000 people annually per country in this region (Table I , right panel).

For comparison, in the Latin America and the Caribbean (LAC) region, the annual value lost in disasters is follows: US$73m geophysical disasters; US$62m lost in hydrological disasters per country/year; about the same amount US$64m lost in meteorological disasters and about US$16m in climate disasters (Table I , middle panel). The populations affected are also smaller than the populations in South and East Asia, with hydrological disasters affecting the most close to 600,000 people per country annually (Table I , middle panel).

The reason why we have decided to focus on the frequency rather than the value lost and the population affected in this study is that the frequency is the only exogenous variable among the three. Both the value lost and the population affected are partially an outcome of disaster preparedness, which is a function of both income levels and the investment levels in the country.

4. Empirical model, data and methodology

To determine the impact of natural disasters on FDI we run two models as follows: a contemporaneous model and a model with "lagged" natural disasters, where the disaster variable is lagged five time periods relative to the period of FDI. Following a methodology by Blonigen (2005), we construct the following empirical equations (1) and (2):

$$\log\left(FDI_{it}^{j}\right) = \beta_0 + \beta_1 \log\left(FDI_{it-1}^{j}\right) + \beta_2\, GDP_{it} + \beta_3\, Demo_{it} + \beta_4\, Nat\mathrm{Re}\,nt_{it} + \beta_5\, Disaster_{it}^{\mathrm{k}} + \mu_i + \eta_t + \varepsilon_{it} \quad (1)$$

$$\log\left(FDI_{it}^{j}\right) = \beta_0 + \beta_1 \log\left(FDI_{it-1}^{j}\right) + \beta_2\, GDP_{it} + \beta_3\, Demo_{it} + \beta_4\, Nat\mathrm{Re}\,nt_{it} + \beta_5\, Disaster_{i,t-5}^{k} + \mu_i + \eta_t + \varepsilon_{it} \quad (2)$$

$$\mu_i \sim i.i.d\left(0, \sigma_{\mu_i}\right), \varepsilon_{it} \sim \text{i.i.d.}(0,\sigma_\varepsilon), E[\mu_i \varepsilon_{it}] = 0.$$

The definitions and sources of the variables are as follows:

- FDI^j_{it} – this refers to the net *inflows of FDI* as a share of GDP in natural logarithm form; the "*j*" superscript is an index, indicting the sector, j = 1, 2, corresponding to manufacturing and services sectors, respectively[5]. The statistical properties of the sectoral FDI by regions are presented in Table II.
- GDP_{it} ‒ *growth rate of GDP per capita* in 2005 US$, purchasing power parity is a proxy for host country market size. This variable is instrumented with a GMM-style matrix to avoid potential endogeneity and reverse causality. The variable is sourced from world development indicators.
- $Demo_{it}$ – *democratic accountability* is a variable associated with the quality of institutions. Democratic accountability is evidence for the presence of checks and balances in the government, specifically in the executive, legislative and judicial branches, as well as of for protection of personal liberties. It is compiled in the International Country Risk Guide (ICRG)[6].
- $\text{NatRent}_{\text{it}}$ – *natural resources rents share of the GDP*. Rents are generated by coal, forest, mineral, natural gas and oil resources. These are estimates based on sources and methods described in "The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium" (World Bank, 2011). We hypothesize that the natural resources endowments impact differently FDI inflows to different sectors.
- *Disasters – natural disasters occurrences* variables are the key explanatory variable, sourced from International Disaster Database EM-DAT[7]. The superscript *"k"* is an index of type of natural disaster, with k=1 to 4 for the four types of disasters. *Meteorological disasters* include extreme temperatures and storms. *Climate disasters* include wild fires and droughts. *Hydrological disasters* include disturbances, caused by movement of surface and subsurface fresh and saltwater. *Geophysical disasters*

Variable	obs	Mean	Std. dev	Min	Max
All countries					
Man. FDI	1,933	2,535.154	9,060.977	−37,967.4	143,274
Ser. FDI	1,732	5,902.806	21,071.99	−52,944.7	415,035
WE					
Man. FDI	482	2,718.082	6,390.076	−37,967.4	52,131.3
Ser. FDI	373	13,681.74	35,794.84	−52,944.7	415,035
EECA					
Man. FDI	299	955.4091	2,638.583	−13,521.5	31,948
Ser. FDI	285	2,639.155	6,152.292	−952.42	67,350
SEAP					
Man. FDI	408	2,778.984	7,916.663	−3,268.86	52,100.5
Ser. FDI	359	4,944.624	12,013.67	−7,328.75	92,406.9
LAC					
Man. FDI	527	988.6761	2,965.329	−2,959	31,664
Ser. FDI	509	1,208.069	3,294.806	−979	30,454

Table II. Sectoral FDI inflows (million US$), summary statistics by regions include landmass movements, earthquakes and volcanic activity. We account for the number of disaster occurrences.

- The variables μ_i and η_t are country and time-specific effects, respectively[8]. The country-specific effects are fixed (within-group) effects. The alternative random effects assume an independent distribution of the explanatory variables from the individual effects. This assumption is violated between $FDI^j_{i,t-1}$ and μ_i.

The method we choose for this study is a dynamic Blundell–Bond "system" GMM estimator. The Blundell–Bond system GMM uses lagged-level observations as instruments for differenced variables and lagged differenced observations as instruments for level variables using a matrix of "internal" instruments. It has one set of instruments to deal with the endogeneity of some regressors and another set to deal with the correlation between the lagged dependent variable and the induced MA(1) error term. A necessary condition for the "system GMM" is that the error term should not be serially correlated of the second-order; otherwise, the standard errors of the instrument estimates grow without bound[9]. Second-order autocorrelation in the error term: $E\left[FDI^j_{i,t-s}(\varepsilon_{it} - \varepsilon_{i,t-1})\right] = 0$; $E\left[GDP_{i,t-s}(\varepsilon_{it} - \varepsilon_{i,t-1})\right] = 0$; $E[x_{i,t-s}(\varepsilon_{it} - \varepsilon_{i,t-1})] = 0$; $E\left[Disaster^k_{i,t-s}(\varepsilon_{it} - \varepsilon_{i,t-1})\right] = 0$ for $s \geq 2$ and $t = 3, \ldots, T$.

The "system GMM" estimator requires one additional condition: even if the unobserved country-specific effect is correlated with the levels of the regressors, it should not be correlated with their differences. The second set of conditions are: $E\left[\left(FDI^j_{i,t-1} - FDI^j_{i,t-2}\right)(\mu_i + \varepsilon_{it})\right] = 0$; $E[(GDP_{i,t-1} - GDP_{i,t-2})(\mu_i + \varepsilon_{it})] = 0$; $E[(x_{i,t-1} - x_{i,t-2})(\mu_i + \varepsilon_{it})] = 0$; $E\left[\left(Disaster_{i,t-1} - Disaster^{\mathrm{k}}_{i,t-2}\right)(\mu_i + \varepsilon_{it})\right] = 0$ [10].

The condition also means that the deviations of the initial values of the independent variables from their long-run values should not be systematically related to the country-specific effects[11].

5. Empirical results

A summary of the key regression coefficients is provided in Table III[12]. The table contains the regression estimates of natural disaster coefficients for all categories of disasters by region. The estimated contemporaneous and lagged effects of disasters are presented in sequential rows, with odd-numbered rows showing contemporaneous and even-numbered rows showing lagged effects coefficients. The pair of contemporaneous-lagged coefficients is being referred to as a "block."

Panels 1 and 2 present results regarding manufacturing and services FDI, respectively. Along the rows, coefficients of four types of disasters as follows: metrological; climate, hydrological and geophysical disasters are presented, paired with the coefficients of the lagged disasters. The geographical regions covered correspond to the Column 1-all countries; Column 2-West Europe; Column 3-Eastern Europe and Central Asia; Column 4-South and East Asia and the Pacific; and Column 5-Latin America and the Caribbean. The full regression results for "All countries" are displayed in Tables IV and V.

As predicted by theory, the contemporaneous effects of natural disasters on FDI are negative. The first row of each block of regression coefficients in Table III presents estimates of contemporaneous disasters, respectively, for manufacturing and for services FDI. An overview of manufacturing FDI regressions shows a pattern of contemporaneous disasters having a negative impact in some geographical regions while lagged disasters, disasters occurring five

Table III. Summary of regression coefficients for contemporaneous and lagged natural disasters

Disaster type	(1) All countries	(2) West Europe	(3) Eastern Europe and Central Asia	(4) South and East Asia and the Pacific	(5) Latin America and the Caribbean
Manuf. FDI (Panel 1)					
(1) Meteorological disasters	*−0.126** (0.0644)*	−0.183 (0.349)	*−1.401*** (0.304)*	−0.114 (0.0878)	−0.0199 (0.141)
(2) Lagged meteorological disasters	−0.0746 (0.0606)	−0.213 (0.399)	*−1.680*** (0.213)*	0.0559 (0.102)	−0.0763 (0.113)
(3) Climate disasters	*−0.253** (0.126)*	0.453 (0.320)	−0.0835 (0.246)	−0.0564 (0.0527)	−0.407 (0.500)
(4) Lagged climate disasters	−0.118 (0.152)	*0.901*** (0.234)*	0.0191 (0.277)	−0.0478 (0.0661)	0.239 (0.249)
(5) Hydrological disasters	−0.0344 (0.102)	0.130 (0.230)	−0.157 (0.194)	0.0716 (0.0550)	−0.0169 (0.0805)
(6) Lagged hydrological disasters	0.0238 (0.0829)	*0.466* (0.264)*	0.161 (0.235)	−0.0693 (0.0651)	−0.138 (0.101)
(7) Geophysical disasters	0.0428 (0.174)	*−0.290*** (0.000)*	*−0.789*** (0.213)*	0.0905 (0.188)	−0.267 (0.389)
(8) Lagged geophysical disasters	0.0348 (0.111)	*1.363*** (0.322)*	*0.500** (0.252)*	0.118 (0.229)	*0.835* (0.440)*
Services FDI (Panel 2)					
(1) Meteorological disasters	−0.0700 (0.0504)	−0.0391 (0.190)	0.0655 (0.670)	−0.0641 (0.121)	0.102 (0.104)
(2) Lagged meteorological disasters	−0.0380 (0.0536)	0.356 (0.254)	−1.099 (0.786)	−0.0153 (0.101)	0.00718 (0.193)
(3) Climate disasters	*−0.177** (0.0855)*	−0.0174 (0.348)	0.334 (0.418)	*−0.180** (0.0753)*	−0.327 (0.292)
(4) Lagged climate disasters	−0.106 (0.0852)	−0.192 (0.321)	−0.374 (0.452)	−0.0813 (0.0704)	*−0.371** (0.170)*
(5) Hydrological disasters	−0.0878 (0.0847)	0.102 (0.117)	−0.236 (0.233)	0.00544 (0.129)	*−0.252*** (0.0939)*
(6) Lagged hydrological disasters	−0.174 (0.116)	*−0.740*** (0.248)*	−0.0388 (0.272)	0.00561 (0.139)	*−0.192** (0.0949)*
(7) Geophysical disasters	−0.0656 (0.0756)	*0.316*** (0.000)*	*−13.06*** (1.96e − 10)*	0.0437 (0.0551)	−0.00727 (0.247)
(8) Lagged geophysical disasters	−0.102 (0.110)	*0.152*** (1.25e−10)*	−1.255 (1.419)	*0.0615* (0.0342)*	−0.163 (0.172)

Notes: Robust standard errors in parentheses; ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table IV. Manufacturing FDI and disasters, sample of "all countries"

Variables	(1) Contemp. metrological disasters	(2) Lagged metrological disasters	(3) Contemp. climate disasters	(4) Lagged climate disasters	(5) Contemp. hydrological disasters	(6) Lagged hydrological disasters	(7) Contemp. geophysical disasters	(8) Lagged geophysical disasters
Lag, ln (FDI Manuf	0.594***	0.493***	0.503***	0.460***	0.315**	0.206	0.214*	0.642***
Share of GDP)	(0.116)	(0.127)	(0.183)	(0.141)	(0.154)	(0.183)	(0.121)	(0.0703)
Growth rate, GDP per cap, 2005 USD$, purchasing power	−1.151	−0.274	−3.850	−0.567	3.658	−1.733	2.181	−2.587
parity	(3.410)	(2.354)	(4.183)	(2.814)	(2.498)	(4.236)	(5.288)	(4.583)
Natural Resources	0.0113	0.00225	0.0155*	0.00531	0.00640	0.00997	0.0167	0.00190
Rent, share of GDP	(0.00968)	(0.00927)	(0.00932)	(0.00643)	(0.00720)	(0.00801)	(0.0126)	(0.00758)
Democratic	−0.0157	−0.0466	−0.0237	−0.0392	0.00491	−0.0352	−0.0724	−0.00752
Accountability	(0.0422)	(0.0535)	(0.0693)	(0.0550)	(0.0592)	(0.0798)	(0.109)	(0.0754)
Ln (disaster	*−0.126***	−0.0746	*−0.253***	−0.118	−0.0344	0.0238	0.0428	0.0348
occurrence)	*(0.0644)*	(0.0606)	*(0.126)*	(0.152)	(0.102)	(0.0829)	(0.174)	(0.111)
Constant	−1.992***	−2.622***	−2.353**	−3.274***	−3.996***	−4.267***	−3.782***	−1.991***
	(0.757)	(0.747)	(1.086)	(0.904)	(0.902)	(1.078)	(0.865)	(0.612)
Observations	483	464	388	355	655	591	222	229
Number of countries	67	69	68	67	74	73	42	43
AR(2)	0.591	0.075	0.035	0.224	0.044	0.190	0.348	0.209
Sargan χ^2	88.93***	184.75***	113.81***	107.37***	164.36***	188.94***	165.09***	143.21***

Notes: Robust standard errors in parentheses; ***$p < 0.01$; **$p < 0.05$; * $p < 0.1$

Table V.
Services FDI and disasters, sample of "all countries"

Variables	(1) Contemp. metrological disasters	(2) Lagged metrological disasters	(3) Contemp. climate disasters	(4) Lagged climate disasters	(5) Contemp. hydrological disasters	(6) Lagged hydrological disasters	(7) Contemp. geophysical disasters	(8) Lagged geophysical disasters
Lag, ln(FDI Services	0.776***	0.720***	0.660***	0.734***	0.746***	0.648***	0.396***	0.523***
Share of GDP)	(0.0783)	(0.116)	(0.110)	(0.0850)	(0.100)	(0.181)	(0.117)	(0.139)
Growth rate, GDP per cap, 2005 US$, purchasing power	−2.147	−2.360	−6.773*	−2.975	−0.247	1.501	−2.011	−0.236
parity	(3.046)	(3.597)	(3.834)	(3.308)	(2.322)	(1.822)	(3.555)	(3.118)
Natural Resources	0.00642	−0.00816	0.0272**	0.00642	0.00328	−0.00235	0.0171	−0.00580
Rent, share of GDP	(0.0112)	(0.00994)	(0.0109)	(0.00837)	(0.00696)	(0.00841)	(0.0118)	(0.0102)
Democratic	−0.00103	−0.0417	0.0644	−0.0136	0.0280	0.00878	−0.0610	−0.0366
Accountability	(0.0321)	(0.0326)	(0.0573)	(0.0483)	(0.0383)	(0.0324)	(0.0441)	(0.0438)
Ln (disaster	−0.0700	−0.0380	*−0.177***	−0.106	−0.0878	−0.174	−0.0656	−0.102
occurrence)	(0.0504)	(0.0536)	*(0.0855)*	(0.0852)	(0.0847)	(0.116)	(0.0756)	(0.110)
Constant	−0.818	−0.533	−2.856***	−2.128	−1.641***	−1.677*	−1.764***	−1.050
	(0.689)	(0.805)	(0.776)	(1.629)	(0.528)	(0.924)	(0.488)	(0.675)
Observations	385	368	299	282	521	492	181	192
Number of countries	67	65	60	62	65	66	33	38
AR(2)	0.909	0.346	0.441	0.204	0.214	0.214	0.620	0.663
Sargan χ^2	155.06***	91.92***	118.85***	133.43***	68.55***	136.78 ***	116.59***	148.22***

Notes: Robust standard errors in parentheses; ***$p < 0.01$; **$p < 0.05$; * $p < 0.1$

years prior, stimulate FDI. Meteorological disasters (Panel 1, Block 1) have negative effects on manufacturing FDI in the regions Eastern Europe and Central Asia and "all countries" (Panel 1, Block 1, Row 1, Columns 1 and 3). The negative effect in Eastern Europe and Central Asia countries does not disappear in the long run. Five years past the disaster, the effect is still present (Panel 1, Block 1, Row 2, Column 3).

There is a negative contemporaneous effect of climate disasters when "all countries" are considered together (Panel 1, Block 2, Row 3, Column 1). Five years past the climate and hydrology disasters, however, industrialized countries of Western Europe recover and increase their manufacturing FDI inflows. The lagged effect of these disasters on manufacturing FDI in Western Europe is positive (Panel 1, Blocks 2 and 3, Rows 4 and 6, Column 2). This is evidence that developed economies have the potential to overturn droughts and floods and rebuild their FDI capacity.

Likewise, geophysical disasters (earthquakes, landslides and volcano eruptions) have immediate negative effects on FDI in the manufacturing sectors in West Europe and in the Eastern Europe and Central Asia countries (Panel 1, Block 4, Row 7, Columns 2 and 3). However, the lagged effects, i.e. the effects five years after the disaster are positive in these countries (Panel 1, Block 4, Row 8, Columns 2 and 3). Therefore, geophysical disasters present some opportunity for rebuilding FDI capacity when other internal conditions are right. In addition, lagged geophysical disasters present a positive opportunity for attracting FDI flows in the process of rebuilding in Latin America and the Caribbean, too (Panel 1, Block 4, Row 8, Column 5).

Overall, manufacturing FDI, which consists of a bigger share of tangible capital assets, appears to suffer from an initial negative impact of natural disasters and recover over time to turn disaster destruction into opportunity for more investment. While climate and hydrology disasters opportunities appear to be used primarily by the countries of West Europe, which are both, economically developed, and geographically less exposed to droughts and floods than some other world regions, the opportunities created by the geophysical disasters arguably the most detrimental kind, appear to be captured by foreign investors in Eastern Europe and Central Asia and Latin America and the Caribbean.

The broad FDI inflow that we analyze is services FDI (Table III , Panel 2). Services FDI can be characterized with a large intangible investment component that we hypothesize, could be less sensitive to disasters. The reaction of services FDI to natural disasters appears to be different from that of manufacturing FDI inflows. First, meteorological disasters appear not to have an impact on services FDI in either contemporaneous or longer term (Panel 2, Block 1, Rows 1 and 2). Unlike the case of manufacturing FDI inflows, climate and hydrology disasters do not a positive effect on services FDI in the long run in any of the geographical regions. Climate disasters appear to produce a negative immediate effect on services FDI in the South and East Asia and the Pacific region that is also seen when all countries are considered together (Panel 2, Block 2, Row 3, Columns 1 and 4). At the same time, climate disasters have a negative lagged effect on services FDI in Latin America and the Caribbean region (Panel 2, Block 2, Row 4, Column 5).

Meanwhile, there is evidence about the detrimental effects of hydrological disasters on services FDI in the Latin America and the Caribbean region, both contemporaneous and lagged coefficients are negative and significant in this region (Panel 2, Block 3, Rows 5 and 6, Column 5). This points to a lack of investment recovery from flood disasters even in the long run. Similar is the situation with West Europe where the long run impact of flood disasters on services FDI is also negative (Panel 2, Block 3, Row 6, Column 2). For West

European countries services FDI are a big share of aggregate FDI inflows and the services sector, in general, plays a bigger role in their economies.

Finally, we analyze the arguably most catastrophic natural disaster group – the geophysical disasters (Panel 2, Block 4). With this group of disasters, which notably included earthquakes and landslides, similarly to manufacturing FDI, we do see some positive impact on services FDI in the long run. First, the imminent impact appears to be mixed- it presents some opportunities for FDI growth in West Europe, but it is negative for services FDI in Eastern Europe and Central Asia (Panel 2, Block 4, Row 7, Columns 2 and 3). The lagged effect of geophysical disasters, however, appears to present an opportunity for more FDI in the tertiary sector for the countries of two regions, such as West Europe and South and East Asia and the Pacific (Panel 2, Block 4, Row 8, Columns 2 and 4).

In summary, the effects of natural disasters on manufacturing and services FDI appear to have some nuances. Manufacturing FDI shows a pattern of being negatively affected immediately after the disaster and use the disaster as an opportunity of rebuilding in a longer term, such as five years. Services FDI do not show such pattern. Some disasters, such as meteorological, have no effect and some, such as climate and floods, have long-lasting negative effects on tertiary sector FDI. For both types of FDI flows manufacturing and services, there is one common theme – the most destructive disasters, the geophysical disasters, have a positive impact on FDI in the long run. This appears to be the case with manufacturing FDI to West Europe, East Europe and Central Asia, and Latin America and the Caribbean and the case with services FDI to West Europe and South and East Asia and the Pacific.

6. Conclusion

In the current study, we investigate the question about the pattern of FDI in a post-natural disaster period, considering a time span of one year and five years. We differentiate between the reaction of manufacturing sector FDI inflows and services sector FDI inflows, which account, respectively, for tangible physical assets and intangible knowledge assets technology transfer. This is the first study that merges the widely-used EM-DAT data set on natural disasters with sector-level data for FDI for 69 countries for 1980-2011 and analyze the response of FDI with a dynamic panel methodology. It is also the first study that both, distinguishes between different kinds of natural disasters as follows: meteorological, climate, hydrological and geophysical, and between different geographical regions such as West Europe, Eastern Europe and Central Asia, South and East Asia and the Pacific, and Latin America and the Caribbean.

Controlling for commonly accepted determinants of FDI, such as output growth, quality of institutions and natural resource abundance, we find that manufacturing FDI shows a pattern of being negatively affected immediately after the disaster and positively in the longer run – a finding that is in unison with the “upgrading destruction” hypothesis we are testing. Services FDI, on the other hand, does not show such pattern. Meteorological disasters have no effect on services FDI and climate and hydrological disasters have long-lasting negative effects. For both types of FDI flows, manufacturing and services, geophysical disasters have a positive impact on FDI in the long run. This appears to be the case with manufacturing FDI to West Europe, East Europe and Central Asia, and Latin America and the Caribbean and the case with services FDI to West Europe and South and East Asia and the Pacific.

The evidence for “upgrading destruction” by natural disasters means replacement of old capital assets and outdated technologies with more advanced one. This means increased productivity in the long run. A capital upgrading also means an increase of wealth for households in the long run. However, all of this is conditioned on proper disaster risk management and disaster preparedness. Countries that are on the path of predictable and repetitive natural disasters are like to suffer from them on a continuous basis. Therefore, all possible capital improvements that follow a disaster should be "locked in" by preventing a severe impact by the next one. Foreign capital, and FDI in particular, help not only by supplying a means of financing but also by building new facilities and infrastructure that are better equipped to withstand the blows of nature.

FDI is one of the main sources of financing for developing countries. FDI is impacted by climate change. The intensifying and increase of frequency of natural disasters not only presents a challenge but also an opportunity for attacking FDI. The destruction of infrastructure and displacement of people result in a negative initial impact and a positive long-run impact of some disasters. Governments need to take advantage of the opportunities created by the need for the replacement and rebuilding of infrastructure and intangible capital. With proper incentives and industry-specific targeted policies, rebuilding can result in upgrading. FDI can be attracted in a targeted way to bring in the necessary external capital and advanced technological knowledge to make upgrading possible.

Notes

1. The list of countries is available in the Appendix.
2. Unavailability of sectoral FDI data for both, the Middle East and North Africa and the Sub Saharan Africa regions, prevents us from including these regions in the study.
3. For example, the conclusion of Horwich (2000) that the economic devastation of the 1995 Kobe earthquake in Japan is not very large in magnitude is based a limited number of post-disaster years.
4. Because of lack of sectoral FDI data, we have excluded the African region from the study.
5. Manufacturing refers to industries belonging to the International Standard Industrial Classification (ISIC), revision 3, divisions 15-37. Services correspond to ISIC divisions 50-99. Services include value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services, such as education, health care and real estate services. Also, included are imputed bank service charges, import duties and any statistical discrepancies noted by national compilers, as well as discrepancies arising from rescaling. The source for these data are a proprietary data set, complied by United Nations Conference on Trade and Development (UNCTAD) and Division of Investment and Enterprise.
6. The working definition of democracy that ICRG uses includes, for example, the following features: a government/executive that has not served more than two successive terms; free and fair elections for the legislature and executive as determined by constitution or statute; active presence of more than one political party and a viable opposition; evidence of checks and balances among the three elements of government, namely, executive, legislative and judicial; evidence of an independent judiciary; and evidence of the protection of personal liberties through constitutional or other legal guarantees, reflects how responsive government is to its people, on the basis that the less responsive it is, the more likely it is that the government will fall, peacefully in a democratic society, but possibly violently in a non-democratic one (ICRG).
7. EM-DAT database D. Guha-Sapir, R. Below, Ph. Hoyois – EM-DAT: The CRED/OFDA International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.
8. The year-dummy are not reported because of space constraints.
9. By construction, the differenced error term is first-order serially correlated even if the original error term is not.

10. x is a vector of the control variables: $Demo_{it}$ and N at $Rent_{it}$.
11. The regressions are run on Stata 14, using the command "xtabond2" and creating instruments with the "ggmstyle" option with two-lag instruments. This is a procedure for reducing the number of instruments suggested by Roodman (2009).
12. The full regression results for the sample of "all countries" are presented in Tables IV and V.

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Further reading

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Toya, H. and Skidmore, M. (2007), "Economic development and the impacts of natural disasters", *Economics Letters*, Vol. 94 No. 1, pp. 20-25.

Appendix

All countries: Albania, Argentina, Australia, Austria, Bangladesh, Belgium, Belize, Bolivia, Brazil, Brunei Darussalam, Bulgaria, Canada, Chile, China, Colombia, Croatia, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, El Salvador, Estonia, Finland, France, Germany, Greece, Guyana, Honduras, Hungary, Iceland, India, Indonesia, Italy, Jamaica, Japan, Kazakhstan, Korea

Rep., Latvia, Lithuania, Macedonia FYR, Malaysia, Mexico, Netherlands, Nicaragua, Norway, Pakistan, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Thailand, Trinidad and Tobago, Turkey, Ukraine, UK, USA, Uruguay, Venezuela and Vietnam.

Western Europe: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Netherlands, Norway, Portugal, Spain, Sweden and UK.

Eastern Europe and Central Asia: Albania, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Macedonia, FYR, Poland, Romania, Russian Federation, Serbia, Slovak Republic, Slovenia and Ukraine.

South and East Asia and the Pacific: Australia, Bangladesh, Brunei Darussalam, Cambodia, China, India, Indonesia, Japan, Korea, Dem. Rep., Lao PDR, Malaysia, Pakistan, Philippines, Singapore, Thailand and Vietnam.

Latin America And the Caribbean: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Dominican Republic, Ecuador, El Salvador, Guyana, Honduras, Jamaica, Mexico, Nicaragua, Paraguay, Peru, Trinidad and Tobago and Uruguay.

Corresponding author
Nadia Doytch can be contacted at: ndoytch@brooklyn.cuny.edu

Short and long-run impacts of climate change on agriculture: an empirical evidence from China

Abbas Ali Chandio
College of Economics, Sichuan Agricultural University – Chengdu Campus, Chengdu, China

Yuansheng Jiang
Sichuan Agricultural University – Chengdu Campus, Chengdu, China

Abdul Rehman
Anhui University, Hefei, China, and

Abdul Rauf
School of Economics and Management, Southeast University, Nanjing, China

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Abstract

Purpose – The climate change effects on agricultural output in different regions of the world and have been debated in the literature of emerging economies. Recently, the agriculture sector has influenced globally through climate change and also hurts all sectors of economies. This study aims to examine and explore the impact of global climate change on agricultural output in China over the period of 1982-2014.

Design/methodology/approach – Different unit root tests including augmented Dickey–Fuller, Phillips–Perron and Kwiatkowski, Phillips, Schmidt and Shin are used to check the order of integration among the study variables. The autoregressive distributed lag (ARDL) bounds testing approach to cointegration and the Johansen cointegration test are applied to assess the association among the study variables with the evidence of long-run and short-run analysis.

Findings – Unit root test estimations confirm that all variables are stationary at the combination of I(0) and I(1). The results show that CO_2 emissions have a significant effect on agricultural output in both long-run and short-run analyses, while temperature and rainfall have a negative effect on agricultural output in the long-run. Among other determinants, the land area under cereal crops, fertilizer consumption, and energy consumption have a positive and significant association with agricultural output in both long-run and short-run analysis. The estimated coefficient of the error correction term is also highly significant.

Research limitations/implications – China's population is multiplying, and in the coming decades, the country will face food safety and security challenges. Possible initiatives are needed to configure the Chinese Government to cope with the adverse effects of climate change on agriculture and ensure adequate food for the growing population. In concise, the analysis specifies that legislators and policy experts should spot that the climate change would transmute the total output factors, accordingly a county or regional specific and crop-specific total factor of production pattern adaptation is indorsed.

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Originality/value – The present empirical study is the first, to the best of the authors' knowledge, to investigate the impact of global climate change on agricultural output in China by using ARDL bounds testing approach to cointegration and Johansen cointegration test.

Keywords China, Climate change, CO_2 emissions, Agricultural output, Cointegration approach

Paper type Research paper

1. Introduction

Agriculture is considered most vulnerable to the global climate change, the security of food is another issue that needs great concern to all humankind, and the influence of climate change on agriculture attracted huge attention (Tao *et al.*, 2006; Wang *et al.*, 2009; Xiong *et al.*, 2007). The agriculture has a dominant source of income for most rural communities and it adopts the adverse effects of climate change to protect the livelihoods of poor rural households and also having an essential role to ensure food security. Adoption can make the rural communities better and become accustomed to climate change and unpredictability, mitigate potential damage and help them to cope with the adverse consequences, thereby significantly reducing vulnerability to climate change (Cline, 2008). The agriculture sector's reliance on climate change is quite important concern for economic development, as the majority of country's population lives in rural areas is engaged with agricultural and non-agricultural related activities (WB, 2014). Farmers constantly find ways to adapt the variations in the weather and climatic conditions. However, environmental and global climate change has expanded the scale needed for farmers to develop and implement resilience strategies (Aiello, 2009; Collier, 2013; Hess, 2003). Adapting to the current agricultural system is one of the ways to avoid climate change risks and protect livelihoods and local food security. Though the type and scope of adaptation strategies vary from region to region, and socio-economic and agro-ecological environments are constantly changing (Abid *et al.*, 2015). Therefore, the production of food is being affected by weather and climate change. It is necessary to study the influence of global climate change to meet the requirements of people and is estimated by 2100; the world population will reach about 10 billion (Boogaard *et al.*, 2014; Keyzer *et al.*, 2002). The agriculture sector is highly associated with the climatic changes, and also causes dangerous activity. Climate variability is the main source of risk for agriculture and food system. The increasing severity of extreme weather and frequent occurrence of widespread defects the agriculture. Farmers often face erratic rainfall, pests and natural disasters. For instance, farmers experience heavy rains, floods, pests, droughts and market prices (Godfray *et al.*, 2010; Huang, 2014; Iqbal *et al.*, 2016; Ullah *et al.*, 2016). On the other side, in most parts of China, climate warming usually shortens the growth cycle of food crops, which leads to demur the average production (Huang *et al.*, 2010; Wang *et al.*, 2014). Because of the numerous seasonal droughts, there is a spatial and temporal gap among precipitation and irrigation, which ensuring the adequate challenges in irrigation and water supply (Zhang *et al.*, 2006). In the future, the climate change in China may bring more uncertainty in the agricultural productivity. Several previous studies in the agronomic modeling literature have shown that yield and yield of main food crops will decline in the numerous future climates (Xiong, 2014). Furthermore, some studies have been conducted to highlight the association of CO_2 emissions with agricultural crops, natural gas and renewable, economic growth and energy consumption (Chandio *et al.*, 2019; Dong *et al.*, 2018; Lin and Xu, 2018; Liu *et al.*, 2016; Luo *et al.*, 2017; Rauf *et al.*, 2018a; Rauf *et al.*, 2018b; Rauf *et al.*, 2018c; Rauf *et al.*, 2018d; Rehman *et al.*, 2019; Wang *et al.*, 2018). However, in this study, authors will investigate the CO_2 emissions with rainfall, temperature and agricultural output by using augmented Dickey–

Fuller (ADF)[1] unit root test for the variable's stationarity and the autoregressive distributed lag (ARDL)[2] bounds testing approach to check the association among the study variables. The time series data was taken from the world development indicators (WDI) to investigate an interrelationship between the variables. The rest of the study is organized as follows: Review of relevant literature is provided in the Section 2, data and methodology are presented in the Section 3, empirical findings of the study and its discussions are described in the Section 4, and Section 5 is conclusion, policy recommendations, and finally, study limitations on Section 6.

2. Existing literature

Indeed, China is considered the most populous country in the world, feeding one-fifth of the world's population and using only 8 per cent of the world's cultivated land. Ensuring food security for the repaid growing population is a long-term priority of the Chinese Government. In China, the demand of foods will continue to increase because of population growth and economic development, while the arable land and other productive resources will cause shrinkage because the agricultural productivity will subject to the climate change (Cline, 2007; Li *et al.*, 2011; Yao *et al.*, 2007). Furthermore, among the other factors such as socio-economic, cultural, institutional characteristics and political that can promote or hinder the adaptation process. The third part refers to the multiple scales of adaptation. Climate adaptive capacity and adaptation strategies vary from plot to farm level, to national and international levels and also differ in size. Therefore, the analysis of a system's adaptive capacity and appropriate adaptation strategies should take into account the scale analysis (Vincent, 2007). Abid *et al.* (2015) reported that livelihoods of the rural households and the yield of major food and cash crops, including wheat, rice, cotton and sugarcane had heavily affected over the past two decades because of variations in the global climate. In developed economies, the concentration of CO_2 is mainly caused by several production and consumption activities. On the other hand, the change in the global climate are largely faced by developing countries, and most of the countries are located in tropical regions and mainly rely on the agricultural sector. Practically, all economic sectors are susceptible to climate change but agriculture is the most. Climate change will address crop productivity issues through changes in the rainfall patterns, sowing and harvest dates, rising temperatures, water supplies and transpiration (Rosegrant *et al.*, 2008; Zenghelis, 2006). The security of food and water supply is greatly vulnerable to rapid change in the climate. In summer, most climate models expect to increase the rainfall. Almost, 75 per cent of the Himalayan glaciers are melted and will disappear by 2035. An upgrade in the strength may result in drought and flooding, respectively. Climate change will adversely affect the production of crops and may contribute to the food security issues (Kirby *et al.*, 2016; Mendelsohn, 2014; Mirza, 1997; Misra, 2014; Pearce *et al.*, 1996; Spash, 2007). In the previous few decades, climate change impact has been evident, mainly in low-income countries. However, it has been pointed out that rural households who have not adopted any strategies have shown that lack of information, access to land and lack of formal agricultural credit are the main factors hindering their adaptation to perceived climate change (Bryan *et al.*, 2009; McCarthy *et al.*, 2001; Smit and Skinner, 2002). Climate change has gained great concern because it can trigger socio-economic disasters. Therefore, assessing the economic vulnerability is the main step in addressing climate change (Field, 2014; Zhang *et al.*, 2011). Furthermore, greenhouse gases also exacerbate climate change, and it is caused by the extra natural solar energy generated by an increase in the ocean heat. This increase in the ocean heat effect the sea level to rise and also cause the sea surface temperature to increase. The diversity of ocean currents and temperatures caused by climate change affects global climate patterns.

However, climate change effects on the oceans suggest that future generations, especially those of small island states, may no longer be able to grow there in a sustainable manner (CCI, 2018). The agronomists have made great efforts to develop adaptation strategies in response to the potential negative impacts of future climate change on agriculture. Wang *et al.* (2014) reported that in the southern regions of China, the introduction of improved new crop varieties with similar climatic conditions is mainly considered a practical approach to combating climate warming. The consequence of climate change to China's agriculture and rural economy cannot be overemphasized. About 750 million people and 250 million rural households in China are directly or indirectly affianced in agricultural activities. The challenges of global climate change and how climate change impacts on the yield of crops are important political and economic issues (Lobell *et al.*, 2007; Peng *et al.*, 2004; Wei *et al.*, 2009; Xiong, 2014). Recently, some authors have investigated the impact of climate change on cereal yield, agriculture and economic growth by using several econometric techniques. Dumrul and Kilicaslan (2017) used the ARDL bounds testing approach and found a positive and significant impact of precipitation on agriculture output while temperature has a negative impact on agricultural output in Turkey. Rahim and Puay (2017) examined the nexus between climate change and economic growth in Malaysia. The time frame for the study was 1983 to 2013. The study analyzed the variable using the unit root tests such as the Dickey–Fuller GLS (DF-GLS) and the ADF, the Johansen cointegration approach (JCA) and vector error correction model (ECM). The variables in the study were the gross domestic product (GDP), precipitation, temperature and arable land. Results of the analysis revealed that there is a long-run cointegration association between the study variables. There is a one-way causality nexus from temperature and arable land to GDP. An empirical study has been conducted in India by Alam (2013), which examined the response of agricultural output to climatic change and its long-run effect on economic growth by using time-series data between 1971 and 2011. An ARDL approach and ECM based procedures has been used to inspect the short and long-run nexus between CO_2 emissions, agricultural output and economic growth. Findings revealed that there is a negative and significant linkage between CO_2 emissions and economic growth while there is a positive and significant association between agricultural output and economic growth. As studied by Asuamah Yeboah *et al.* (2015) examined the impact of CO_2 emissions on cereal production in Ghana by using the ARDL approach. The time-series data for Ghana from the period of 1961-2010 is used, findings of the empirical analysis revealed that there is a significant unenthusiastic linkage between CO_2 emissions and cereal production while there are a positive and significant short and long-run relationships between cereal production and income. Furthermore, Rehman *et al.* (2019) study on CO_2 emissions and agricultural productivity in Pakistan by using an ARDL bounds testing approach results demonstrated that cropped area, energy usage, fertilizer offtake, GDP per capita and water availability showed a significant association with CO_2 emissions, while improved seed distribution and total food grains reveled a negative association with CO_2 emissions in Pakistan. To the best of our knowledge, no empirical study has been done in the context of China to investigate the effects of climate change on agricultural output. This study aims to examine the short-run and long-run interconnection between climate change factors and agricultural output in the context of China.

3. Methodology and data

The ARDL[2] approach was first introduced by the Charemza and Deadman (1992) and then further enhanced by Pesaran and Shin (1998) and Pesaran *et al.* (2001) The ARDL[2] approach has several advantages over the traditional cointegration methods such as Engle and

Granger cointegration approach (EGCA)[3](1987), JCA[4](1988) and Johansen and Juselius cointegration approach (JJCA)[5](1990). It takes a small sample size and simultaneity biases in the association between the variables. The main problem in the traditional cointegration approaches was that it requires all the study variables to be non-stationary at I(0) but should be stationary at the same order. The modern cointegration approach like the ARDL overcomes regarding this issue, as it is appropriate regardless of the order of integration among the variables, whether at levels I(0) or at first difference I(1) or both of mixed order of integration. Furthermore, this modern approach also has another advantage in choosing the appropriate numbers of lags for the empirical model. These estimable features validate the usage of ARDL approach to obtain robust estimates. To investigate the association of climate change factors including CO_2 emissions, temperature and rainfall on agriculture in China throughout 1982-2014, the following model can be specified as:

$$\mathrm{AGR_t} = \mathrm{f}(\mathrm{CO_{2t}}, \mathrm{TEMP_t}, \mathrm{RF_t}, \quad \mathrm{CL_t}, \quad FC_t, \quad EN_t, RP_t) \tag{1}$$

In the equation (1), $\mathrm{AGR_t}$ indicates the agriculture value added, $\mathrm{CO_{2t}}$ represents the CO_2 emissions, $\mathrm{TEMP_t}$ represents the average temperature, $\mathrm{RF_t}$ represents the rainfall, $\mathrm{CL_t}$ represents the land area under cereal crops, $\mathrm{FC_t}$ denotes the fertilizers consumption, $\mathrm{EN_t}$ indicates the energy consumption and $\mathrm{RP_t}$ represents the rural population, respectively. Equation (1) can also be written as:

$$\begin{aligned}\mathrm{AGR_t} = {} & \lambda_0 + \lambda_1 \mathrm{CO_{2t}} + \lambda_2 \mathrm{TEMP_t} + \lambda_3 \mathrm{RF_t} + \lambda_4 \mathrm{CL_t} + \lambda_5 FC_t + \lambda_6 EN_t \\ & + \lambda_7 RP_t + \mu_t\end{aligned} \tag{2}$$

To reduce the multicollinearity and volatility of the annual time series data, this study used all the variables in their nature logarithmic form. By applying natural logarithm to equation (2), a log-linear model is specified as follows:

$$\begin{aligned}\mathrm{LnAGR_t} = {} & \lambda_0 + \lambda_1 \mathrm{LnCO_{2t}} + \lambda_2 \mathrm{LnTEMP_t} + \lambda_3 \mathrm{LnRF_t} + \lambda_4 \mathrm{LnCL_t} + \lambda_5 \mathrm{LnFC_t} \\ & + \lambda_6 \mathrm{LnEN_t} + \lambda_7 \mathrm{LnRP_t} + \mu_t\end{aligned} \tag{3}$$

Mainly, the ARDL model contains two main steps for assessing a long-run association. Step 1 is to examine the presence of a long-run association between the study variables. Equation (4) represents the specification of ARDL model may follow as:

$$\begin{aligned}\Delta lnAGR_t = {} & \alpha_0 + \sum_{i=1}^{p} \beta_{1j} \Delta lnAGR_{t-k} + \sum_{i=0}^{p} \beta_{2j} \Delta lnCO_{2t-k} + \sum_{i=0}^{p} \beta_{3j} \Delta lnTEMP_{t-k} \\ & + \sum_{i=0}^{p} \beta_{4j} \Delta lnRF_{t-k} + \sum_{i=0}^{p} \beta_{5j} \Delta lnCL_{t-k} + \sum_{i=0}^{p} \beta_{6j} \Delta lnFC_{t-k} \\ & + \sum_{i=0}^{p} \beta_{7j} \Delta lnEN_{t-k} + \sum_{i=0}^{p} \beta_{8j} \Delta lnRP_{t-k} + \lambda_1 lnAGR_{t-1} + \lambda_2 lnCO_{2t-1} \\ & + \lambda_3 lnTEMP_{t-1} + \lambda_4 lnRF_{t-1} + \lambda_5 lnCL_{t-1} + \lambda_6 lnFC_{t-1} + \lambda_7 lnEN_{t-1} \\ & + \lambda_8 lnRP_{t-1} + \varepsilon_t\end{aligned} \tag{4}$$

where α_0 represents the intercept, p denotes the lag order, Δ stands for the first difference operator and ε_t denotes the error term. This study used F-test to check the long-run equilibrium link among LnAGR, LnCO_2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP. The null hypothesis of no cointegration between LnAGR, LnCO_2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP is *H0*: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = \delta_8 = 0$ against the alternative hypothesis *H1*: $\delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq \delta_7 \neq \delta_8 \neq 0$. According to Pesaran *et al.* (2001), the calculated F-test or Wald-test is matched with the values of lower bound and upper bound. If the computed F-test goes above the upper level of bound, the null hypothesis of no cointegration between LnAGR, LnCO_2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP is rejected. If the computed F-test is less to the upper level of bound, it cannot reject the null hypothesis of no cointegration between LnAGR, LnCO_2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP. However, If the computed F-test lies between the lower and upper level of the bands, the null hypothesis of no cointegration of LnAGR, LnCO_2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP becomes inconclusive, which either can be testified through Johansen cointegration approach (1990) or by using the cumulative sum recursive residuals (CUSUM)[6] and cumulative of square of recursive residuals (CUSUMSQ)[7] to check the constancy of the cointegration (Brown *et al.*, 1975). Step 2 is to assess the short-run association between CO_2 emissions, temperature, rainfall, land area under cereal crop, fertilizers consumption, energy consumption, rural population and agriculture in China, the following ECM in ARDL formulation can be expressed as:

$$\begin{aligned}\Delta lnAGR_t = \alpha_0 &+ \sum_{i=1}^{p} \beta_{1j} \Delta lnAGR_{t-k} + \sum_{i=0}^{p} \beta_{2j} \Delta lnCO_{2t-k} + \sum_{i=0}^{p} \beta_{3j} \Delta lnTEMP_{t-k} \\ &+ \sum_{i=0}^{p} \beta_{4j} \Delta lnRF_{t-k} + \sum_{i=0}^{p} \beta_{5j} \Delta lnCL_{t-k} + \sum_{i=0}^{p} \beta_{6j} \Delta lnFC_{t-k} \\ &+ \sum_{i=0}^{p} \beta_{7j} \Delta lnEN_{t-k} + \sum_{i=0}^{p} \beta_{8j} \Delta lnRP_{t-k} + \alpha ECM_{t-1} + \varepsilon_t\end{aligned} \tag{5}$$

This study used the annual time-series data of the global climate change factors and other control variables for China over the period 1982-2014. It was collected from the WDI[8]. The details of the study variables are presented in Table I. Figure 1 presents the time plots of the study variables used in the analysis.

4. Empirical results and discussions

The results of the descriptive statistics are shown in Table II, which indicates that all variables are normally distributed in the model with constant variance and zero covariance as showed by JB statistics. Similarly, the results of the correlation matrix are displayed in Table III, which shows that CO_2 emissions, temperature, fertilizer consumption and energy consumption are positively associated with agriculture. A positive correlation established between temperature, rainfall and fertilizer consumption and CO_2 emissions. A pre-condition is that to check the integration order among the study variables. The estimation of the unit root tests ensures that there are no study variables are static and integrated in the order of I(2) to prevent false outcomes. According to Ouattara (2004), if any of the study variables are stationary and integrated at I(2), then the computed ARDL bounds and F-statistics of the cointegration becomes meaningless. The critical bounds in the ARDL approach are based on an assumption, i.e. all study variables should be stationary and integrated at I(0) or I(1) (Pesaran *et al.*, 2001).

The study has applied different unit root tests such as the Kwiatkowski, Phillips, Schmidt and Shin (KPSS), the ADF and the Phillips–Perron (PP), to find out the integration status of the study variables. The estimated results of the unit root tests (e.g. KPSS, ADF and PP) including at the levels of variables, and then at the first differences are reported in Table IV. The results disclose that all variables are stationary at the combination of I(0) and I(1). It means that stationary properties may display a robust long-run association among the variables and supports to apply the ARDL approach.

This study examines the long-run relationship between climate change factors and other control variables by using the ARDL approach. The initial step is to apply for the selection of appropriate lag length. The results of several selection criteria are presented in Table V, and the order of optimal lag length is decided by adopting the Schwarz information criterion.

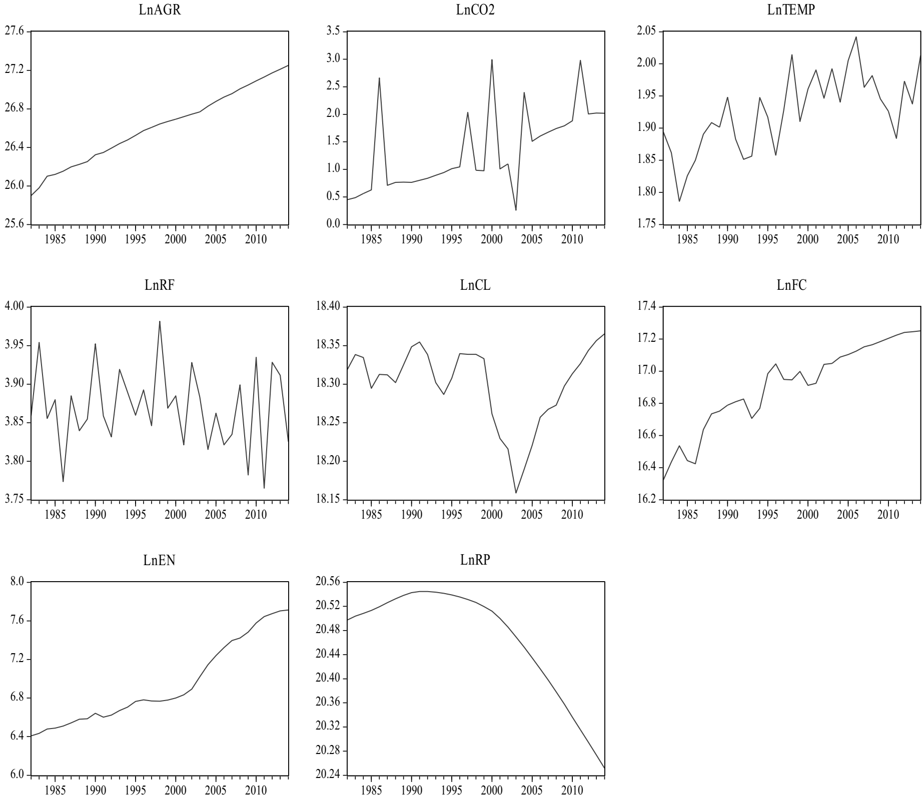
The outcomes of ARDL bounds tests shown in the Table VI illustrating that the computed F-tests are 4.828, 7.142, 11.339, 7.214, 3.782, 5.486 and 7.344 go above the upper critical bound at the 1 and 10 per cent levels of significance; when LnAGR, LnCO_2, LnRF, LnCL, LnFC, LnEN and LnRP are used as dependent variables, while it means that there are seven cointegration vectors and we may reject the hypothesis of no cointegration. The outcomes of ARDL bounds test for cointegration confirms a long-run association between agriculture (LnAGR), CO_2 emissions (LnCO_2), average annual rainfall (LnRF), land under cereal crops (LnCL), fertilizers consumption (LnFC), energy consumption (LnEN) and rural population (LnRP) in China.

Furthermore, in this study, JJCA[6] has used to check the robustness of long-run connection and test results are reported in Table VII. The estimates are suggesting a rejection of the null hypothesis of no cointegration in the model because the values of the trace statistic and maximum eigenvalue are higher than the critical values at the 1 and 5 per cent levels of significance. Hence, an alternative hypothesis will be accepted where long-run association presence is valid between the agricultural output and climate change factors, by counting with other control variables in China.

The results of the long-run analysis are shown in Table VIII (Panel A). The results of the long-run analysis are shown in Table VIII (Panel A). The estimated results display that CO_2 emissions have a positive long-run impact on the agricultural output at 5 per cent significance level. A 1 per cent increase in CO_2 emissions can increase the agricultural output by 0.061325 per cent. This result is similar to Janjua *et al.* (2014). Similarly, the estimated long-run coefficients of temperature and rainfall are showing negative linkage with the agricultural output. It shows that temperature and rainfall increase, agricultural output decrease as well. The findings of this study are in line with

Variables	Explanation	Data source
AGR	Agriculture value added (constant 2010 US$)	WDI
CO_2	CO_2 emissions (metric tons per capita)	WDI
TEMP	Average annual temperature (°C)	WDI
RF	Average annual rainfall (mm)	WDI
CL	Land area under cereal crops (hectares)	WDI
FC	Fertilizers consumption (kilograms per hectare of arable land)	WDI
EN	Energy consumption (kg of oil equivalent per capita)	WDI
RP	Rural population (% of total population)	WDI

Table I.
Variables description



Notes: LnAGR; LnCO2; LnTEMP; LnRF; LnCL, LnFC, LnEN and LnRP refer, respectively, the natural logarithm of agriculture value added; the natural logarithm of emission of carbon dioxide; the natural logarithm of average temperature; the natural logarithm of average rainfall; the natural logarithm of land area under cereal crops; the natural logarithm of fertilizers consumption; the natural logarithm of energy consumption, and the natural logarithm of rural population

Figure 1.
Time plots series of the study variables

Ahmed and Schmitz (2011), Mahmood *et al.* (2012), Peng *et al.* (2004), Saseendran *et al.* (2000) and their studies concluded that temperature has a negative impact on the rice production. Similarly, Ali *et al.* (2017) reported that maximum temperature has an adverse impact on wheat production. Furthermore, the coefficient of land area under cereal crops to agricultural output is positive and significant. In the long-run analysis, the area under cereal crops will play a key role in boosting agricultural output. The outcomes reveal that a 1 per cent increase in the land area of cereal crops, agricultural output increased by 1.277362 per cent. The result of this study is in line with Ahmad (2011) and Chandio *et al.* (2016). Likewise, fertilizers can also play a significant role to cope with any adverse effect toward agricultural output in the long-run. Appropriate usage of fertilizers could improve soil nutrition and soil fertility. The effect of fertilizer consumption on agricultural output is also notable. For example, this study finds out that a 1 per cent increase in fertilizer consumption could raise agricultural output by 0.383519 per cent. This result is similar to Chandio *et al.* (2018)b; Rehman *et al.* (2017). In the

Variables	LnAGR	$LnCO_2$	LnTEMP	LnRF	LnCL	LnFC	LnEN	LnRP
Mean	26.61624	1.342909	1.925240	3.869605	18.29998	16.90989	6.939429	20.43596
Median	26.64200	1.014000	1.928104	3.862299	18.31267	16.94882	6.778244	20.50836
Maximum	27.25100	2.992000	2.041862	3.981598	18.36525	17.25190	7.712770	20.54471
Minimum	25.90000	0.260000	1.785513	3.764940	18.15864	16.32307	6.408249	19.25171
Std. dev	0.381321	0.744014	0.060125	0.052059	0.050815	0.268164	0.425825	0.227454
Skewness	−0.062979	0.695057	−0.171595	0.038230	−1.109558	−0.606185	0.624162	−4.464143
Kurtosis	1.959597	2.504884	2.508000	2.629923	3.538084	2.351016	1.946547	23.71776
Jarque-B	1.510168	2.994138	0.494785	0.196355	7.169266	2.600156	3.668606	699.7924
Probability	0.469971	0.223785	0.780834	0.906488	0.027747	0.272511	0.159725	0.000000
Observations	33	33	33	33	33	33	33	33

Notes: LnAGR; $LnCO_2$; LnTEMP; LnRF; LnCL, LnFC, LnEN and LnRP refer, respectively, the natural logarithm of agriculture value added; the natural logarithm of emission of CO_2; the natural logarithm of average temperature; the natural logarithm of average rainfall; the natural logarithm of land area under cereal crops; the natural logarithm of fertilizers consumption; the natural logarithm of energy consumption and the natural logarithm of rural population
Source: The authors' calculation

Table II. Descriptive statistics and correlation analysis

long-run estimation, energy consumption and rural population as a proxy of the labor force are indicating positive linkage with agricultural output. The energy consumption and rural population are statistically insignificant with the coefficients of 0.032058 and 0.084486. It implies that a 1 per cent increase in energy consumption and rural population will increase the agricultural output by 0.032058-0.084486 per cent, respectively.

The outcomes of the short-run estimation are also shown in Table VIII (Panel B). The estimated short-run results reveal that the explanatory variables (such as CO_2 emissions, land under cereal production, fertilizer consumption and energy consumption) are statistically positive and significant that influenced the agricultural output. Among all the repressors, the coefficient of the impact of CO_2 emissions in the long-run, as well as in the short-run analysis on agricultural value added is distinguished. The short-run coefficient of CO_2 emissions is 0.010115, which means a 1 per cent increase in CO_2 emissions will boost the output of about 0.010115 per cent. In the short-run estimation, this study does not find out any significant or negative effect of climate change factors, for instance, temperature and rainfall, on agricultural output. This result is similar to Janjua *et al.* (2014). In both long-run and short-run analyses, the results found that land area (area under cereal crops) is highly significant and showing to enhance the agricultural output in China. The land as a prime input displays its coefficient 0.366496; this implies a 1 per cent increase in area under cereal crops will boost the output almost by 0.366496 per cent. Similarly, in the long-run and short-run estimation, fertilizer consumption has a positive and significant influence on agricultural output. The short-run coefficient of energy consumption is 0.287169, concerning to agricultural output is highly significant at 1 per cent, which is in the line of earlier findings (Abbas and Choudhury, 2013; Chandio *et al.*, 2018a; Lili *et al.*, 2011). These estimates suggest that a 1 per cent increase in energy consumption, agricultural output increases about by 0.287169 per cent. The error correction term ECM_{t-1} denotes the speed of adjustment toward the long-run equilibrium from any short-run shock in the repressors. The elasticity estimates of ECM_{t-1} is negative, and it is highly significant at the 1 per cent. The estimated results of diagnostic tests in the ARDL model, which are also described in Table VIII (Panel C) shows the model has passed several diagnostic tests (for example, χ^2 SERIAL, χ^2NORMAL, χ^2ARCH, χ^2White and χ^2 RESET), respectively. For the stability of

Table III.
Correlation analysis

Variables	LnAGR	$LnCO_2$	LnTEMP	LnRF
LnAGR	1.000000			
$LnCO_2$	0.617587*** [4.371985] (0.0001)	1.000000		
LnTEMP	0.653508*** [4.807084] (0.0000)	0.259548 [1.496384] (0.1447)	1.000000	
LnRF	−0.100633 [−0.563161] (0.5774)	−0.386284** [−2.331724] (0.0264)	0.090667 [0.506898] (0.6158)	1.000000
LnCL	−0.181616 [−1.028296] (0.3118)	−0.027397 [−0.152599] (0.8797)	−0.400964** [−2.436949] (0.0207)	0.146113* [0.822347] (0.4172)
LnFC	0.960188*** [19.13723] (0.0000)	0.511468*** [3.314006] (0.0023)	0.647124*** [4.726011] (0.0000)	−0.065914 [−0.367793] (0.7155)
LnEN	0.955049*** [17.93731] (0.0000)	0.615140*** [4.344086] (0.0001)	0.568548*** [3.847980] (0.0006)	−0.139392 [−0.783756] (0.4391)
LnRP		−0.346058** [−2.053661] (0.0485)	−0.363643** [−2.173476] (0.0375)	0.172236 [0.973519] (0.3378)

Notes: The values of *t*-statistics are displayed in [] and the values of probability are shown in (). ***, ** and * denote the significant levels at 1, 5 and 10%, respectively
Source: The authors' calculations

(*continued*)

Variables	LnCL	LnFC	LnEN	LnRP
LnAGR				
$LnCO_2$				
LnTEMP				
LnRF				
LnCL	1.000000			
LnFC	−0.179751 [−1.017382] (0.3168)	1.000000		
LnEN	−0.094059 [−0.526028] (0.6026)	0.884769*** [10.57053] (0.0000)	1.000000	
LnRP	−0.194587 [−1.104525] (0.2779)	−0.446625*** [−2.779305] (0.0092)	−0.617711*** [−4.373407] (0.0001)	1.000000

Table III.

Variables	Deterministic component	KPSS	ADF	PP
LnAGR	Intercept	0.672293**	−1.570751	−1.528224
$LnCO_2$	Intercept	0.750558***	−1.427441	−4.372953***
LnTEMP	Intercept	0.587621**	−2.647526*	−2.468565
LnRF	Intercept	0.149017	−8.242308***	−8.242308***
LnCL	Intercept	0.475547**	−2.594935	−7.551133***
LnFC	Intercept	0.744697***	−2.994883**	−3.145724**
LnEN	Intercept	0.626046**	0.222899	1.046705
LnRP	Intercept	0.624057**	−1.321710	3.147199
LnAGR	Trend and intercept	0.117321	−2.103766	−4.366799***
$LnCO_2$	Trend and intercept	0.205014**	−6.491043***	−7.836178***
LnTEMP	Trend and intercept	0.115075	−4.224725**	−4.231295***
LnRF	Trend and intercept	0.088666	−8.246404***	−8.246404***
LnCL	Trend and intercept	0.193082**	−2.249160	−6.634182***
LnFC	Trend and intercept	0.168940**	−3.456561*	−3.008186
LnEN	Trend and intercept	0.181219**	−1.748692	−1.300633
LnRP	Trend and intercept	0.195166**	−2.372337	−0.148453
ΔLnAGR	Intercept	0.229273	−5.093066***	−5.200618***
$\Delta LnCO_2$	Intercept	0.235533	−5.925019***	−8.553507***
ΔLnTEMP	Intercept	0.129931	−6.448628***	−11.42700***
ΔLnRF	Intercept	0.513000***	−5.495487***	−6.166705***
ΔLnCL	Intercept	0.607482**	−4.385566***	−2.659282*
ΔLnFC	Intercept	0.500000**	−3.859721***	−7.445075***
ΔLnEN	Intercept	0.301828	−2.786180*	−2.787239*
ΔLnRP	Intercept	0.416955*	−0.355692	−0.359966
ΔLnAGR	Trend and intercept	0.125228*	−5.049756***	−5.091460***
$\Delta LnCO_2$	Trend and intercept	0.229399***	−5.800776***	−7.005102***
ΔLnTEMP	Trend and intercept	0.081803	−6.366362***	−10.90011***
ΔLnRF	Trend and intercept	0.536700***	−5.311940***	−5.435658***
ΔLnCL	Trend and intercept	0.197214**	−2.619441	−1.853489
ΔLnFC	Trend and intercept	0.352003***	−4.867117***	−11.21217***
ΔLnEN	Trend and intercept	0.083175	−5.206732***	−10.01048***
ΔLnRP	Trend and intercept	0.130864*	−3.342693*	6.964039***

Notes: KPSS; ADF and PP represent the Kwiatkowski, Phillips, Schmidt and Shin test; the augmented Dickey–Fuller test and the Phillips–Perron test. ***, ** and * denote the significant levels at 1, 5 and 10%, respectively
Source: The authors' calculations

Table IV.
Unit root tests results

Lag	LogL	LR	FPE	AIC	SC	HQ
0	273.0696	NA	5.17e−18	−17.1012	−16.7312	−16.9806
1	584.6489	442.2415	6.86e−25	−33.0741	−29.7435*	−31.9884
2	693.1771	98.0254*	9.98e-26*	−35.9469*	−29.6558	−33.8961*

Note: *Lag order selected by the criterion
Source: The authors' calculations

Table V.
VAR Lag length selection

the ARDL model, this study used CUSUM and CUSUMSQ tests suggested by Brown *et al.* (1975). Figures 2 and 3 show the plot of both stability tests such as CUSUM and CUSUMSQ that fall inside the critical boundaries at 5 per cent level of significance. Hence, it means that the estimated parameters of the model are stable over the periods.

Table VI. Results of ARDL bounds testing to cointegration

Variables	LnAGR	$LnCO_2$	LnTEMP	LnRF	LnCL	LnFC	LnEN	LnRP
F-statistics	4.8289***	7.1426***	2.739003	11.3391***	7.2146***	3.7827*	5.4862***	7.3442***
Optimal lag structure	(1, 1, 1, 0, 0, 1, 1, 1)	(1, 0, 1, 0, 0, 0, 0, 0)	(1, 0, 0, 0, 0, 0, 1, 0)	(1, 0, 0, 0, 0, 0, 1, 0)	(1, 0, 1, 1, 0, 1, 0, 1)	(1, 1, 0, 1, 0, 1, 0, 1)	(1, 0, 1, 0, 0, 0, 1, 1)	(1, 1, 0, 0, 0, 1, 0, 1)
Critical values	1%	5%	10%					
Lower bounds I(0)	2.96	2.32	2.03					
Upper bounds I(1)	4.26	3.84	3.13					
Diagnostic tests								
R^2	0.71859	0.7536	0.515594	0.8263	0.7840	0.7041	0.7721	0.9747
Adj-R^2	0.5260	0.6572	0.326044	0.7584	0.6544	0.5267	0.6528	0.9615
F^2 *statistic*	3.7321**	7.8186***	2.720096**	12.1645***	6.0514***	3.9675***	6.4713***	8.7784***

Notes: *** and * denote the significant levels at 1 and 10%, respectively
Source: The authors' calculations

Hypothesis	Test statistic	5% CV	*p*-value
Trace statistic			
$r \leq 0$	287.3931***	159.5297	0.0000
$r \leq 1$	205.2882***	125.6154	0.0000
$r \leq 2$	142.8606***	95.75366	0.0000
$r \leq 3$	95.02472***	69.81889	0.0001
$r \leq 4$	51.60431**	47.85613	0.0213
$r \leq 5$	25.78058	29.79707	0.1354
$r \leq 6$	10.00833	15.49471	0.2801
$r \leq 7$	0.032574	3.841466	0.8567
Maximum eigenvalue			
$r \leq 0$	82.10488***	52.36261	0.0000
$r \leq 1$	62.42757***	46.23142	0.0005
$r \leq 2$	47.83589***	40.07757	0.0055
$r \leq 3$	43.42041***	33.87687	0.0027
$r \leq 4$	25.82373	27.58434	0.0826
$r \leq 5$	15.77224	21.13162	0.2384
$r \leq 6$	9.975757	14.26460	0.2135
$r \leq 7$	0.032574	3.841466	0.8567

Notes: *** and **denote 1 and 5% levels of significance, respectively.
Source: The authors' calculations

Table VII. Results of the Johansen cointegration test

5. Conclusion and policy implications

Climate change is projected to unfavorably distress to the agricultural output and countryside incomes in an economy. Therefore, sensible adaptation is looked-for to diminish the potential sufferers in agricultural productivity. The main aim of this empirical study was to assess the association of climate change impacts on the agricultural output in China over the period of 1982-2014. The study used several unit root tests including the KPSS, the ADF and the PP to check variables stationarity, while the ARDL approach was used to check the causality association between the study variables with long-run and short-run analysis. Unit root test estimations confirmed that all variables are stationary at the combination of I(0) and I(1). Furthermore, the results of the ARDL approach showed the long-run association between agricultural output, CO_2 emissions, temperature, rainfall, land area under cereal crops, fertilizer consumption, energy consumption and the rural population at 1, 5 and 10 per cent levels of significance. The analysis results of the long-run and short-run coefficients show that CO_2 emissions, land area under cereal crops, fertilizer consumption and energy consumption have a positive impact on the agricultural value added. On the other hand, temperature and rainfall have a negative effect on agricultural value added in the long-run but have a positive effect in the short-run. Based on the findings of current study, it is recommended that possible steps should be taken from the Government of China to adopt new policies and modern technology regarding accurate weather forecasting, and precautionary and direct actions are also needed to develop and underpin an improved irrigation system. The construction of farmland also needed to improve to address future climate change.

In concise, the analysis specifies that legislators and policy experts should spot that the climate change would transmute the total output factors, accordingly a county or regional specific and crop-specific total factor of production pattern adaptation is indorsed. In general, climate change has hostile effects on the yield of the main food crops. Thus, the

Regressors	Coefficient	Standard error	t-ratio	Probability
	Dependent variable: lnAGR; selected model: ARDL (1, 1, 1, 0, 0, 1, 1, 1)			
Panel A: long-run estimation				
$LnCO_2$	0.061325**	0.025531	2.402036	0.0267
LnTEMP	−0.142749	0.262364	−0.544087	0.5927
LnRF	−0.687591*	0.361563	−1.901719	0.0725
LnCL	1.277362**	0.516779	2.471777	0.0231
LnFC	0.383519**	0.141095	2.718160	0.0136
LnEN	0.032058	0.214315	0.149586	0.8827
LnRP	0.084486	0.533271	0.158431	0.8758
C	−7.759671	12.206394	−0.635705	0.5326
Panel B: short-run estimation				
$\Delta LnCO_2$	0.010115**	0.004975	2.033183	0.0562
ΔLnTEMP	0.063575	0.060118	1.057493	0.3035
ΔLnRF	0.080722	0.061896	1.304152	0.2078
ΔLnCL	0.366496***	0.116836	3.136829	0.0054
ΔLnFC	0.110038**	0.048459	2.270722	0.0350
ΔLnEN	0.287169***	0.104579	2.745959	0.0128
ΔLnRP	−6.471040***	1.308158	−4.946680	0.0001
ECM(−1)	−0.286916***	0.051357	−5.586710	0.0000
Panel C: residual diagnostic tests				
R^2 0.7294				
F-stat 4.2166***				
DW-statistic 2.5560				
χ^2SERIAL 1.3597 (0.2833)				
χ^2NORMAL 1.5738 (0.4552)				
χ^2ARCH 0.3619 (0.6995)				
χ^2White 1.0691 (0.4358)				
χ^2RESET 1.4675 (0.1595)				
CUSUM stable				
CUSUM square stable				

Note: ***, ** and *indicate significance levels at 1, 5 and 10%, respectively
Source: The authors' calculations

Table VIII. Long-run and short-run coefficients using the ARDL model

government should propose some solid strategies in this regard to attaining the sustainable productivity of main food crops by familiarizing the modern agriculture technological approaches. In addition, being China's population is multiplying, and in the coming decades, the country will face food security challenges. Therefore, the possible initiatives are also needed to constitute Chinese Government to cope with the adverse effects of climate change on agriculture and ensure adequate food for such massive population.

On the whole, the study also approves and calculates that climate change adaptation for agriculture productivity would offer extensive paybacks to the agriculturalists through upgraded proceeds and to society via better-quality food surety. However, agriculturalists are so far powerless to be blessed with all compensations of accustom because of several restrictions and absence of knowledge on enhanced adaptation possibilities. At this point, the Chinese administration, private formed companies and non-governmental organizations can perform a key part in focusing these restrictions by way of vagarious coordination for capacity building and schooling of agriculturalists, effortless access to micro and macro climate-specific knowledge and understanding on better-quality adjustment processes.

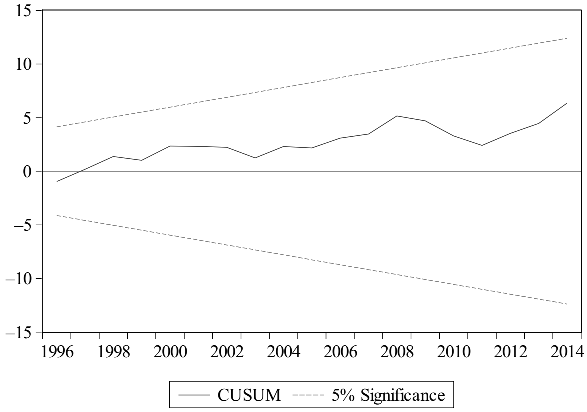


Figure 2.
Plot of CUSUM for ARDL (1, 1, 1, 0, 0, 1, 1, 1) model

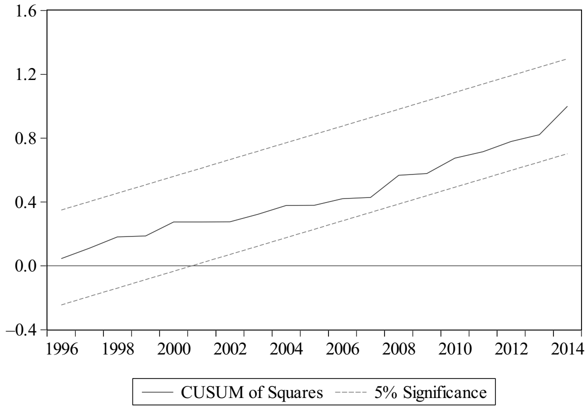


Figure 3.
Plot of CUSUMSQ for ARDL (1, 1, 1, 0, 0, 1, 1, 1)

Supplementary, agricultural guidelines need to be restructured based on modern technological research and consideration should also be granted to resource-restrained and small-tier agriculturalists, who constitute in excess of two-thirds of the entire agricultural inhabitants in China. All these inferences may spread to improved adaptation of food crops to climate change and possibly will adept to sponsor the agriculturalists for expanding their crop yields and certify the homegrown food safety.

6. Limitations

The study has used a countrywide data set, which could not illustrate the factual portrait of the influence of climate change on unlike agro-environmental regions. Thus, to grasp the counties and regional disparities into consideration, area or zones-specific research investigations should be performed for better insights. The aggregated and disaggregated yields corps studies should be conducted to evaluate the impacts of climate change on such dissimilar food crops. The association between CO_2 emissions and the yield of cereal crops should be examined by using the latest econometric techniques in future studies, as the present study considered agricultural output.

Notes

1. See Augmented Dickey-Fuller (1979).
2. The ARDL bounds testing approach of cointegration.
3. See EGCA (Engle and Granger, 1987).
4. See CA (Johansen, 1988).
5. See JJCA (Johansen and Juselius, 1990).
6. CUSUM.
7. CUSUMSQ.
8. See WDI (WDI, 2014).

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Corresponding author
Yuansheng Jiang can be contacted at: yjiang@sicau.edu.cn

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Local knowledge based perceptions on climate change and its impacts in the Rakaposhi valley of Gilgit-Baltistan, Pakistan

Laxmi Dutt Bhatta, Erica Udas, Babar Khan, Anila Ajmal, Roheela Amir and Sunita Ranabhat
(Author affiliations can be found at the end of the article)

Abstract

Purpose – The purpose of this paper is to understand local perceptions on climate change and its impacts on biodiversity, rangeland, agriculture and human health.

Design/methodology/approach – A household survey with 300 interviewees and focus group discussions with key stakeholders were conducted and validated at two steps, using the climate data from the nearest weather stations and reviewing literatures, to correlate the local perceptions on climate change and its impacts.

Findings – Majority of the respondents reported an increase in temperature and change in the precipitation pattern with increased hazardous incidences such as floods, avalanches and landslides. Climate change directly impacted plant distribution, species composition, disease and pest infestation, forage availability, agricultural productivity and human health risks related to infectious vector-borne diseases.

Research limitations/implications – Because of the remoteness and difficult terrain, there are insufficient local weather stations in the mountains providing inadequate scientific data, thus requiring extrapolation from nearest stations for long-term climate data monitoring.

Practical implications – The research findings recommend taking immediate actions to develop local climate change adaptation strategies through a participatory approach that would enable local communities to strengthen their adaptive capacity and resilience.

Social implications – Local knowledge-based perceptions on climate change and its impacts on social, ecological and economic sectors could help scientists, practitioners and policymakers to understand the

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ground reality and respond accordingly through effective planning and implementing adaptive measures including policy formulation.

Originality/value – This research focuses on combining local knowledge-based perceptions and climate science to elaborate the impacts of climate change in a localised context in Rakaposhi Valley in Karakoram Mountains of Pakistan.

Keywords Agriculture, Biodiversity, Climate change, Human-health, Karakoram mountains, Vulnerability

Paper type Research paper

1. Introduction

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013) indicated that the global mean surface temperature has increased by 0.84°C since 1880. This has led to a global threat, i.e. climate change, resulting in substantial socio-economic and ecological impacts, especially in the mountain region. The world's mountains are hotspots of biodiversity and provide climatically different life zones across short elevation distances (Körner, 2004; Fort, 2015). About 10 per cent of the world's population directly depends on mountain resources for their livelihood and well-being (Schild, 2008). The mountainous regions have considerably warmed during the past century, and the temperature rise is expected to continue, whereas precipitation projections show a differential pattern – where some regions are expected to get more rainfall and others less (Kohler *et al.*, 2014). In the changing climate scenario, the future of mountain biodiversity, whether be wild or cultivated, may become site-specific to different ecosystems, and it is likely that there will be increased exposure to multiple hazards because of frequently occurring extreme events such as floods, avalanches and landslides, which will threaten both livelihoods and infrastructure (Kohler *et al.*, 2014).

The mountains in Karakoram–Hindu Kush Himalaya (HKH) are also sensitive to the impacts of climate change. Over a century, the mean temperature in the HKH region has changed at a rate of 0.10°C per decade (Ren *et al.*, 2017). Climate projections suggest that the temperature will increase 1-2°C by 2050, and the precipitation patterns will change with longer and erratic monsoon and less frequent but more intense rainfall (Lutz *et al.*, 2014; Shrestha *et al.*, 2015). Because the HKH region is considered an important storehouse of freshwater, the impacts of climate change will, however, not only limit to freshwater availability to 240 million people upstream and 1.9 billion living downstream (Sharma *et al.*, 2018) but will also affect the livelihoods, agricultural productivity, biodiversity including plant phenology (physiology, reproductive and metabolic changes), population and their habitats (Körner, 2004; Xu *et al.*, 2009; Ahmad *et al.*, 2012; Ali *et al.*, 2017). Visible effects of climate change in the HKH region has been observed through changes in phenology and reduced agriculture production of some major crops in some regions of HKH (Webb and Stokes, 2012; Hart *et al.*, 2014). Wangda and Ohsawa (2010) reported that due to climate change there is probability of shifting of evergreen broad-leaf species from upper limit of 2900 m (current) to higher altitudes in future. Similarly, climate change has affected the daily activities and livelihoods of local communities. According to Suberi *et al.* (2018), local people of the mountain reported low crop production and encroachment of invasive species that hamper agricultural production. However, generalising climate projection findings and the possible impacts of climate change particularly in the mountains brings a larger uncertainty because of its orographic nature that provides micro-climatic conditions along the elevation gradient. In addition, except for a few areas in the HKH, there is still huge data gap on historical climate, which prevents an in-depth understanding of climate variability and its feedback mechanism, further limiting the validation of climate models and projection of future scenarios (Ren and Shrestha, 2017). Thus, local knowledge and perceptions of local communities are very crucial to understand the changing climate in many remote areas of the HKH mountain region (Khan *et al.*, 2011). Local knowledge-based perceptions on climate change are essential to develop enabling policies, effective communication strategies and socially accepted technologies to minimise risks and reduce climate vulnerability (Whitmarsh and Capstick, 2018).

In Gilgit-Baltistan, formerly known as Northern West Frontier province of Pakistan, there are only nine observatories for weather reporting (Pakistan Meteorological Department, 2018), which means that the climate data is scanty and the impacts of climate change may vary in the fragile mountainous areas due to a sharp altitudinal gradient, mostly being site-specific. Rakaposhi Valley, located in Nagar District of Gilgit-Baltistan, is reported as especially vulnerable to climate change and its associated hazards include glacier lake outburst floods (GLOFs), flash floods, avalanches, landslides, droughts, erosion, cloud burst and extreme weather spells (WWF, 2010, 2015a). Extreme climatic events in the area have repeatedly affected major agricultural crops, pastures, infrastructure and livelihoods of the local communities over the past 30 years (WWF, 2015a). There are no any local weather stations in the valley, except the one recently installed by the Water and Power Development Authority (WAPDA) at Hoper, and given the rugged terrain with steep geography, the spatio-temporal climate may vary from the nearest weather observatory. In this context, understanding local community's perceptions on climate change and its impacts on livelihoods including effects on different ecosystems is very important to generate baseline information and develop adaptation strategies. Such local knowledge-based perceptions provide opportunities for policymakers, social development organisations and private sectors to effectively plan, design and implement adaptation programs by minimising risks and hazards. This study, therefore, attempts to provide a systematic analysis of the perceptions of local communities in Rakaposhi Valley to generate a baseline information on changing climate patterns and their direct impact on biodiversity, rangelands, agriculture, including risks to human health. A qualitative research approach was adopted to document the community perceptions on climate change and its impacts. However, the climate data from nearest locations was retrieved because of the absence of local weather stations in the valley and relevant literatures were reviewed to validate the perception findings.

2. Methodology

2.1 Study area

Rakaposhi Valley is located in Nagar District of Gilgit-Baltistan, approximately 80 km north of Gilgit town in Pakistan (Nafees *et al.*, 2014). The valley comprises five villages including Pisan, Yal, Massot, Ghulmet and Minapin with population of 8,500 people living in 906 households (WWF, 2015b). Most of them are agro-pastoralists, highly dependent on mountain farming and livestock herding to earn bread and butter for their families (Khan, 2012). The valley has diverse ecosystems including alpine and sub-alpine pastures, alluvial plains, glaciers, peaks and high-altitude wetlands. Rakaposhi Peak, 7,788 m asl, is a jewel in the crown of the valley. Major species recorded in the area include snow leopard, Siberian ibex, Indian grey wolf, red fox, snow partridge and raptors (Figure 1).

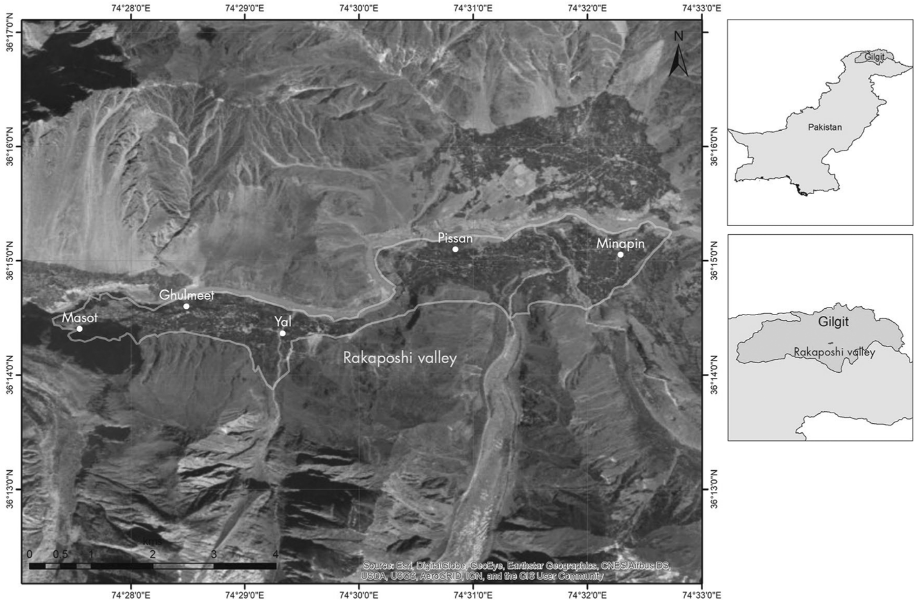


Figure 1.
Map of Rakaposhi Valley in Hunza-Nagar District, Gilgit-Baltistan, Pakistan

Source: ICIMOD, 2019

2.2 Data collection and analysis

A qualitative research method was adopted to document the community perceptions on climate change and its impacts in Rakaposhi Valley (WWF, 2010). Social survey methods such as structured and semi-structured interviews and focus group discussions (FDGs) were used during field visits in the year 2015 to collect primary data. A similar method has been used for recording climate change perception of local communities in many studies (Chaudhary *et al.*, 2011; Sujkahu *et al.*, 2016; Egbe *et al.*, 2014; Joshi *et al.*, 2013). Face-to-face interviews were held with 300 respondents, randomly sampled covering 33 per cent of the total households. The respondents in the interviews and FGDs were key stakeholders such as herders, village elderly people, school teachers and youth including both women and men. About 30 min to maximum 1 h time was allocated for each interview depending on the knowledge of the respondents. Different qualitative questions were asked to better understand the impact of climate change on biodiversity, agriculture, rangelands and health of the communities in Rakaposhi Valley, including their perceptions on the changing climate.

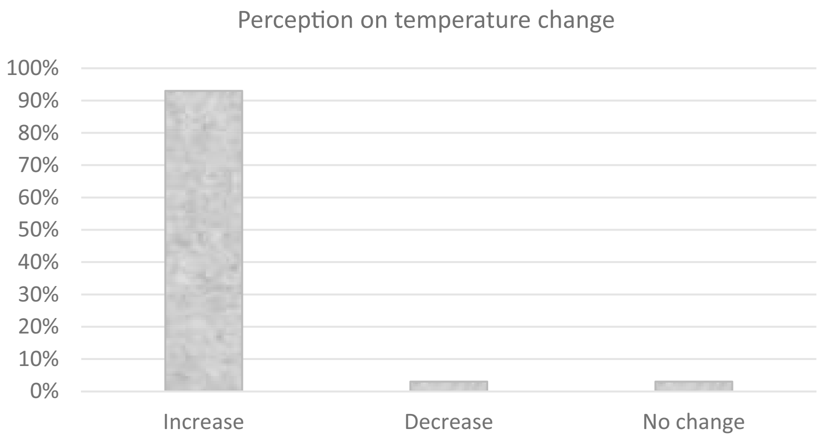
On the other hand, the climate change perceptions of the communities were validated with the daily total sum of precipitation and average temperature data from the study area. The data was retrieved from the ICIMOD's Regional Database System using a 10×10 km^2 spatial resolution for a period of 30 years from 1981 to 2010 (Lutz and Immerzeel, 2016). A linear regression trend analysis was performed for both precipitation and temperature data, where $y = a + bX$ was defined by a (the intercept) and trend b (the slope). The slope of this linear regression provides the rate of change in the given climatic parameters.

Additionally, a thorough literature review was conducted to further validate the community perceptions on the impacts of climate change on biodiversity, rangelands, agriculture and human health. Finally, Microsoft Excel 2013 was used for climate change perception data analysis and developing the output tables and graphs.

3. Results and discussion

3.1 Temperature trend

About 93 per cent of the respondents argued that they witnessed an increase in mean annual temperature over the past 25 years, perhaps due to climate change (Figure 2). To validate this perception from a majority of the respondents, a historical average temperature trend from 1981 to 2010 was analysed in the study area. A linear regression trend analysis showed that both winter and summer are getting warmer at the rate of 0.05°C and 0.02°C, respectively, over the past 30 years (Figure 3). In Gilgit-Baltistan, the mean winter temperature increased at the rate of 0.044°C, which showed a similar trend to that in Rakaposhi Valley; however, in contrast, the summer temperature in Gilgit-Baltistan showed a declining rate of 0.026°C (WWF, 2008). On the other hand, several other studies reported a warming trend in the high mountains and in the Himalaya, with minimum temperatures increasing faster than the maximum, and such increases are greater in the higher elevation (Shrestha *et al.*, 1999; Bhutiyani *et al.*, 2007; Fan *et al.*, 2010). Additionally, it should be noted that the differences on elevation and spatial variation in high mountains, including the effect of seasonality at the temporal scale, could have greater impacts on surface warming, mostly at higher altitudes (Rangwala and Miller, 2012). For example, a significant seasonal variability was observed in Tibetan plateau where the winter warming rate is almost double



Source: Survey (2015)

Figure 2. Community perception on climate change impacts on the temperature pattern

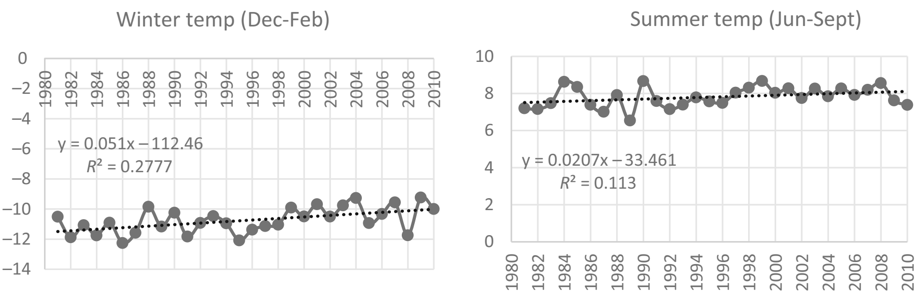


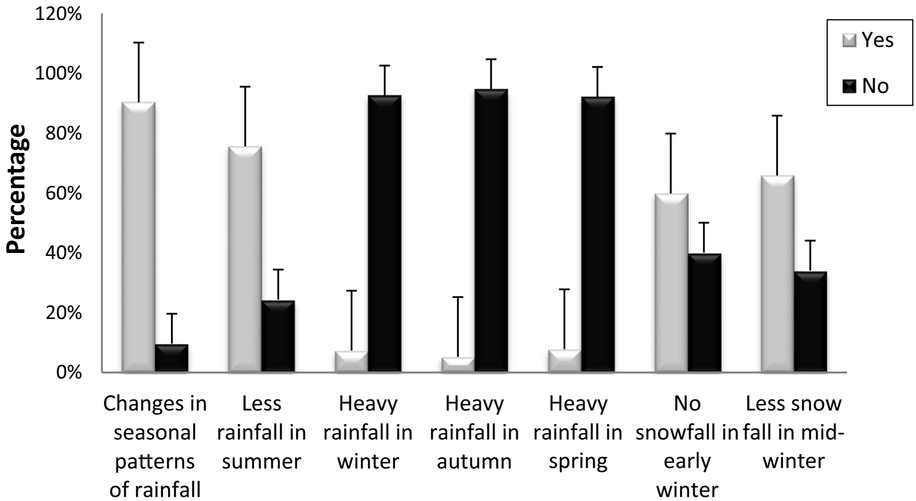
Figure 3. Average winter and summer temperature trends over 30 years

the annual mean warming rate (Liu and Chen, 2000). Likewise, the western Himalayan region in India also showed higher winter warming between 1971 and 2007 compared to the rest of India (Kothawale *et al.*, 2010). These findings are similar to the current study, where the winter warming rate is higher than the summer, and this also matches with the perception from majority of the respondents.

3.2 Precipitation trend

About 90 per cent of respondents stated that the precipitation pattern has changed in Rakaposhi Valley over the past 25 years (Figure 4). Majority of the respondents indicated that they have witnessed an increase in rainfall during winter and spring, whereas a decrease in summer rainfall. On the other hand, 59 per cent respondents indicated that there has been no snowfall during early winter and 65 per cent believed that there is only less snowfall during the mid-winter season.

In Pakistan, there had been strong drought spells in terms of length and intensity throughout the country from 1998 to 2002 because of the El Nino effect (Ahmed and Schmitz, 2011; Naheed and Rasul, 2011). A study in the Karakoram mountain range found that the winter rainfall increased from 1961 to 1999, whereas the summer rainfall decreased (Archer and Fowler, 2004). Naheed and Rasul (2011) found that the percentage of the rainfall variability coefficient in northern Pakistan gradually increased from 1960 to 1999 but, decreased during 2000-2009. Another study from the northern part of Pakistan showed an increase in the rainfall pattern both in summer and winter seasons (Hashmi *et al.*, 2012). This is similar to the findings of the precipitation trend analysis done from 1981 to 2010 in Rakaposhi Valley, where both summer monsoon and winter rainfall trends showed increase over 30 years; however, the amount of rainfall received during the summer was less than that of the winter rainfall (Figure 5). This could be the reason that although the summer rainfall trend was slightly increasing, the community perceived that they witnessed less rainfall in summer compared to that in the winter season.



Source: Survey (2015)

Figure 4.
Community perception on climate change impacts on the rainfall pattern

3.3 Hazard risks

Pakistan is one of the natural disaster prone countries, falling on sixth place in the world (Ahmad *et al.*, 2011). All of the provinces in Pakistan, including Gilgit–Baltistan, are vulnerable to geological and hydro-metrological hazards (Ahmad *et al.*, 2011). The mountainous geography and fragile environment of Gilgit-Baltistan further increase the vulnerability to different hazard risks (WWF, 2010). In terms of hazard risks in Rakaposhi Valley, majority of respondents reported that the frequencies of avalanches, landslides and floods have increased, whereas droughts, flash floods and glacier lake outburst flood (GLOF) events decreased over the past 25 years (Figure 6). Although GLOFs are common in Gilgit-Baltistan with more than 35 GLOFs observed in past two centuries with an increasing frequency in the recent years, such natural hazards have not been reported in Rakaposhi Valley from 1990 to 2012 (Din *et al.*, 2014), perhaps due to local micro-climatic conditions resulting in less glacial lake formation in the valley. Hence, the community perception also reported a decrease in the occurrence of GLOF events. Concurrently, high temperature and high frequency of floods due to heavy rainfall are permanent features of Hunza-Nagar District and Rakaposhi Valley (WWF, 2015a). Severe floods have been reported in the

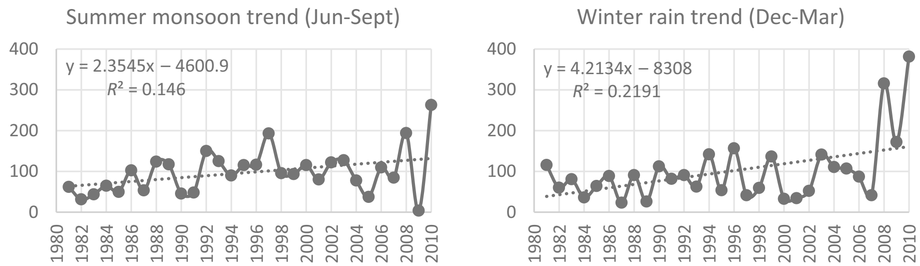
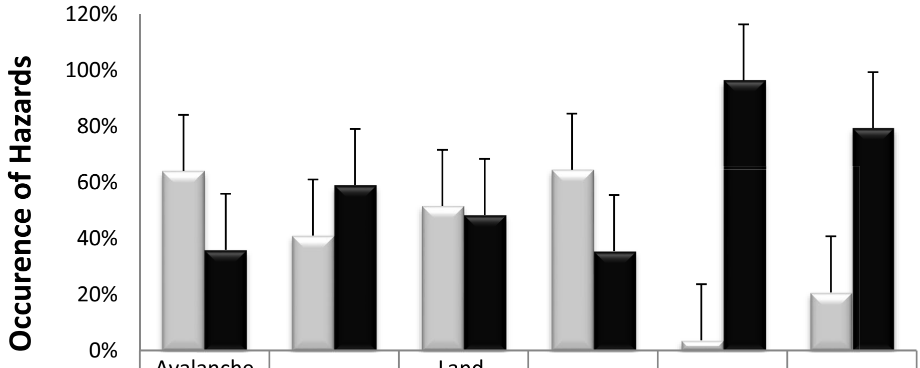


Figure 5.
Trend of summer monsoon and winter rain over 30 years



	Avalanches	FlashFlood	Land sliding	Floods	Droughts	GLOFs
Increase	64.05%	41.01%	51.61%	64.51%	3.68%	20.73%
Decrease	35.95%	58.99%	48.39%	35.49%	96.32%	79.27%

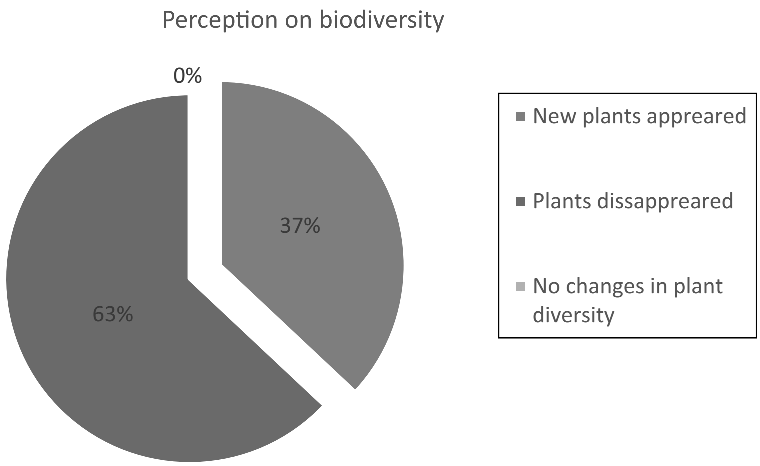
Source: Survey (2015)

Figure 6.
Climate change and community perception on the hazard risks

country during 1950, 1956, 1957, 1973, 1976, 1978, 1988, 1992, 2006 and 2010 with the latter having greater impacts, resulting in highest number of death tolls, injuries and property damages (Ahmad *et al.*, 2011; Hashmi *et al.*, 2012). The 2010 flood inundated low-lying areas of 347 villages in Gilgit-Baltistan with 183 death toll, damaging 3,157 houses and destroying about 7,900 ha cropped land (Hashmi *et al.*, 2012). The flood is attributed to the heavy rainfall because of changes in the climate and monsoon pattern as well as deforestation and construction of dams (Hashmi *et al.*, 2012).

3.4 Climate change impacts on biodiversity

The respondents from focus group discussions reported that the impact of climate change has altered plant distribution, abundance and flowering periods in Rakaposhi Valley. Likewise, about 63 per cent of the total respondents interviewed reported that due to climate change some domestic as well as wild plants have disappeared from the study area, whereas 37 per cent claimed seeing few species that were never seen before in the study area over the past 25 years (Figure 7). In addition, some new fruit trees such as apples, cherry, grapes, peach and apricot have been introduced in the area, which were not part of the local plant diversity. A detailed forest inventory in Gilgit-Baltistan showed higher tree species diversity with Simpson's index value of 0.813 (Ismail *et al.*, 2018). On the other hand, rapid glacier melt due to climate change has caused habitat loss of many floral and faunal species and also interrupted migratory routes of several migrating species (Khan and Ali, 2011). Climate change has also influenced plant phenology, i.e. physiology, reproduction and metabolism, in the Himalaya and its sister ranges (Burkett *et al.*, 2005). Therefore, climate change has direct impact on the mountainous floral community (Xu *et al.*, 2009) and it has been observed that various mountain vegetation types are shifting from lower to higher altitudes because of a lack of tolerance to higher temperatures (Sanz-elorza *et al.*, 2003). Furthermore, it is difficult to estimate the actual effect of climate change in the mountain because of uncertainties related to climate scenarios and non-linear feedback between the impacts on different sectors (Nogués-Bravo *et al.*, 2007). So, several systematic ecological research studies



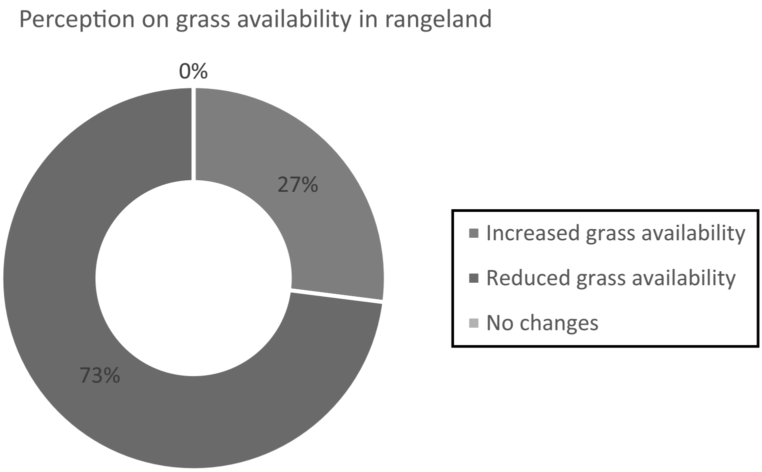
Source: Survey (2015)

Figure 7.
Perception on climate change impacts on the biodiversity

and joint monitoring programs should be conducted to gather knowledge on the impacts of climate change and mountain biodiversity (Ishaq *et al.*, 2015).

3.5 Climate change impacts on rangeland

Gilgit-Baltistan offers 35 per cent rangeland, which is approximately one third of its total area (Khan, 2013). However, there is lack of evidence-based knowledge on the impacts of climate change on rangeland and pastoralism, limiting the effective management for development of the livestock industry. The grazing pressure is very high in these alpine rangelands during the summer season, and this pressure concurrently shifts to dry temperate rangelands during autumn and early spring (Omer *et al.*, 2006). In Rakaposhi Valley, 73 per cent of the respondents reported a decline in forage productivity in the alpine and sub-alpine rangelands over the past 25 years, whereas 27 per cent respondents claimed having well-flourished forage, which might be due to the moist southern aspects or prevailing micro-climatic conditions in these areas. The findings from group discussions revealed that the availability of grasses and fodders in the rangeland was subjected to changing climatic patterns, especially with respect to the precipitation such as snowfall and rainfall. The decline in growth rate of forage has a strong correlation either with droughts or diminishing water resource availability for irrigation, including degradation of rangelands due to overgrazing and excessive removal of natural vegetation for firewood, animal bedding and feeding. In addition, intrusion of invasive and non-palatable species further shrank the grazing land, causing shortage of feed and fodder for the livestock. In Gilgit-Baltistan, the major changes were particularly observed in terms of species composition, distribution and productivity of the rangelands (Khan, 2003; Shaheen *et al.*, 2011; Joshi *et al.*, 2013; Khan, 2013). Less availability of grasses and fodders and diminishing productivity directly affected animal health (Thornton *et al.*, 2009), and the herders have now changed their traditional grazing patterns as an adaptive measure (Joshi *et al.*, 2013), which ultimately resulted in lower household economy and food insecurity (Figure 8).



Source: Survey (2015)

Figure 8.
Perception on climate change impact on the availability of grasses in rangelands

3.6 Climate change impacts on agriculture and crop productivity

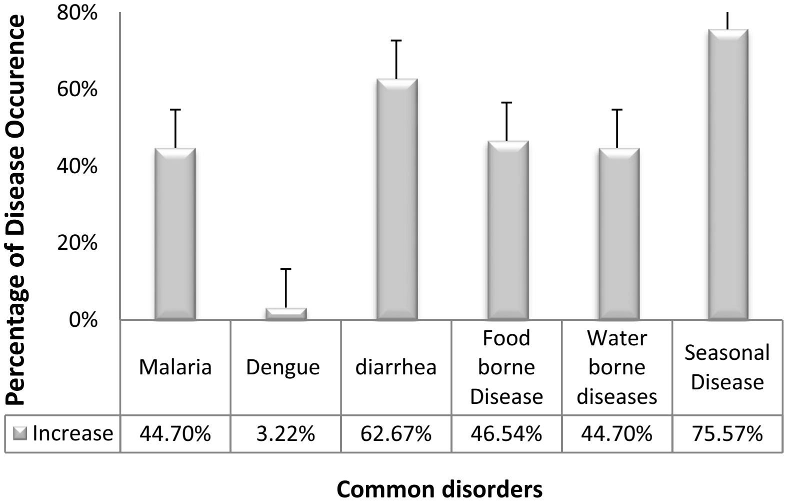
In Pakistan, wheat, rice and maize crops from the agriculture sector contributed positively to the GDP from 1985 to 2015 (Chandio *et al.*, 2016). Agriculture is the second largest sector, accounting for more than 21 per cent of the GDP, and the largest employer, absorbing 45 per cent of labour force (IFAD, 2015). However, the agriculture sector is likely to be most sensitive to climate change because of extreme weather events such as increased temperature, severe droughts or floods, and increased attack of disease pests and soil degradation (Smit and Skinner, 2002; Farooqi *et al.*, 2005), causing threats to agricultural productivity and ultimately leading to food insecurity. Climate change directly impacts the productivity of agricultural crops through shortening of the growing period, losses in yield due to extreme climatic events, changes in river flows and land degradation (Iqbal *et al.*, 2009). Because there is high variability in rainfall, particularly during pre- and post-monsoon seasons, it poses challenges to farmers, mainly in the rain-fed areas, resulting in crop failure or loss in yield (Naheed and Rasul, 2011).

In Rakaposhi Valley, 54 per cent of respondents in the interview reported that the agricultural productivity had decreased over the past 25 years, whereas 46 per cent stated increase in the productivity. Focus group discussions further revealed that a variety of new crops and vegetables such as beans, cabbage, Canadian wheat, carrot, garlic, red beans, maize, potato, pulses and turnips were introduced by the state and other development actors during the late eighties and early nineties. The introduction of new crops has consequently increased diseases and pest attack that seriously damaged apples and apricots, which provide major income to the local communities. Abbas *et al.* (2018) highlighted that replacement of traditional crops by high-yielding varieties in Gilgit-Baltistan has increased disease pest infestation, for example, late blight, early blight, nematodes and leaf roll virus affecting potatoes; gummosis disease affecting apricots, almonds, plums and peaches; and crown gall disease affecting cherries. In addition, some studies showed that the warming trend in high mountains in northern Pakistan has positive impacts on the yield of wheat and other winter crops such as barley because of prolonged growing degree days and shortened growing season length (Hussain *et al.*, 2005; Hussain and Mudasser, 2007). Alternatively, in the wheat-growing regions of southern Pakistan such as Punjab and Sind, a model simulation showed that one degree increase in temperature reduced the yield by 44 kg per hectare (Ahmed and Schmitz, 2011). A recent study on climate change impacts on agricultural productivity of major crops in Pakistan showed negative influence of rainfall, whereas both positive and negative influences of temperature (Ali *et al.*, 2017). Climate change, therefore, may have differential impacts on crop yields, depending on different agro-ecological zones, crop cultivars and varieties.

Furthermore, the respondents in the focus group discussions reported loss in soil fertility owing to the excessive use of inorganic fertilisers such as urea, nitrate and diammonium phosphate (DAP), causing soil desertification. The use of such inorganic fertilisers and pesticides started to increase over the past three decades in the study area; first, it aimed to improve the crop yields, but later, its inefficient use eventually resulted in loss of soil fertility.

3.7 Climate change and risks to human health

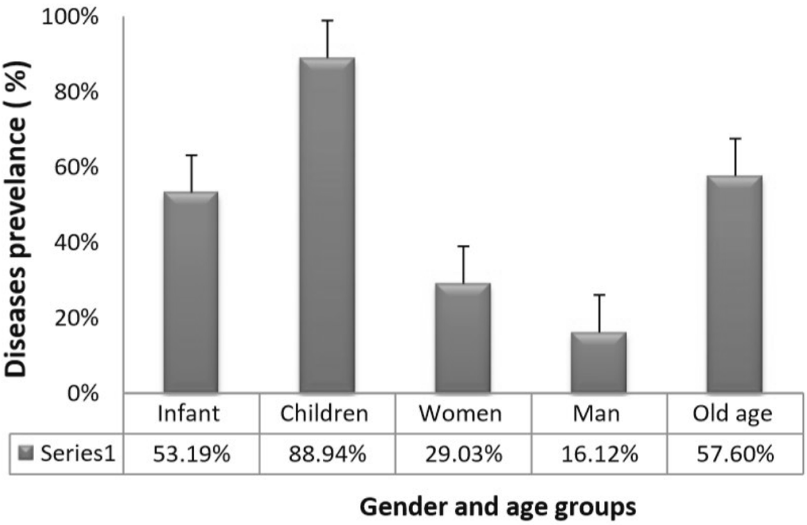
Outbreaks of seasonal and water-borne diseases such as diarrhoea, malaria and dengue were frequently found in the valley, whereas an increase in flu and typhoid were also witnessed during the study years, perhaps due to changing climatic conditions, water contamination and air pollution (Figure 9). Although 37.17 per cent respondents stated that climate change was the major cause of such diseases, whereas 29.35 per cent of the respondents believed that lack of facilities was the major reason. The warmer temperature



Source: Survey (2015)

Figure 9.
Trend of climate-change-induced water-borne diseases

could increase higher incidences of heat-related cardiovascular and respiratory diseases, whereas wetter conditions could increase infectious vector-borne diseases such as malaria, dengue, yellow fever and encephalitis (Farooqi *et al.*, 2005; Malik *et al.*, 2012). Moreover, infants, children and elderly people are amongst the major sufferers in the study area (Figure 10), which could be due to their low immunity, physical weakness, low adaptation to



Source: Survey (2015)

Figure 10.
Occurrence of infectious diseases in different age groups and gender

extreme weather conditions and lack of medical facilities. Malik *et al.* (2012) also reported that elderly people and urban poor in Pakistan are highly vulnerable to the risk of heat-wave-related morbidity and mortality as a result of increasing temperature. In Gilgit-Baltistan and other parts of Pakistan, climate change has significantly increased water-borne diseases because of the erratic floods contaminating drinking water from the streams and rivers (WWF, 2010). A study on climate change vulnerability analysis by agro-ecological zonation in Pakistan showed that health risks in the northern part of the country were mainly related to diarrhoea and gastroenteritis, skin and eye infections, acute respiratory infections and malaria (Malik *et al.*, 2012).

4. Conclusion

Climate change has been greatly affecting people's life and life-supporting systems in Rakhaposhi Valley, increasing vulnerability by manifolds. Uncertain weather patterns and extreme events with the increasing frequency and intensity have adversely affected human health, livelihoods, biodiversity and ecosystems in the Karakoram Mountains. It is very important to understand multidimensional nature of the drivers of change, responses and feedback mechanisms to be able to reduce the vulnerability, which is induced due to not only climate change impacts but also socio-political and economic changes in the region. Because the local communities hold immense traditional knowledge, and they are the ones directly affected by the impacts of the changes including climate change, their participation is very crucial in planning, designing and implementing adaptive measures as well as contributing to policy making. Furthermore, the climate change perception study provides researchers, practitioners and decision makers a clear insight into the local emerging issues, risks and vulnerabilities. To respond to such uncertain risks and vulnerabilities, it is recommended to strengthen the capacity of local communities and encourage them to use customised technologies that use combined science and traditional knowledge so that they can enhance their adaptive capacity and build resilience against existing as well as emerging climate risks. Additionally, it is highly recommended to develop area-specific climate change adaptation strategies for tackling emerging environmental concerns and building local capacities so that communities could manage risks and diversify livelihood options through preparedness and recovery, for example, by adopting climate smart agriculture, soil conservation, irrigation water management, livestock and pasture management, high-value horticulture, product diversification and promoting renewable energy.

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Author affiliations

Laxmi Dutt Bhatta, International Centre for Integrated Mountain Development, Kathmandu, Nepal

Erica Udas, International Centre for Integrated Mountain Development, Kathmandu, Nepal

Babar Khan, WWF Pakistan, Lahore, Pakistan

Anila Ajmal, Deutsche WeltHungerHilfe, Islamabad, Pakistan

Roheela Amir, Universiti Kebangsaan Malaysia, Bangi, Malaysia, and

Sunita Ranabhat, International Centre for Integrated Mountain Development, Kathmandu, Nepal

Corresponding author

Laxmi Dutt Bhatta can be contacted at: Laxmi.Bhatta@icimod.org

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Determinants of adoption of climate-smart agriculture technologies in rice production in Vietnam

Nhat Lam Duyen Tran
VNU School of Interdisciplinary Studies, Vietnam National University, Hanoi, Vietnam

Roberto F. Rañola, Jr
University of the Philippines Los Baños (UPLB), Laguna, Philippines

Bjoern Ole Sander
International Rice Research Institute (IRRI), Hanoi, Vietnam

Wassmann Reiner
International Rice Research Institute (IRRI), Laguna, Philippines

Dinh Tien Nguyen
VNU University of Economics and Business, Vietnam National University, Hanoi, Vietnam, and

Nguyen Khanh Ngoc Nong
University of the Philippines Los Baños (UPLB), Laguna, Philippines

Abstract

Purpose – In recent years, climate-smart agriculture (CSA) was introduced to Vietnam to enhance farmers' resilience and adaptation to climate change. Among the climate-smart agricultural technologies (CSATs) introduced were water-saving techniques and improved stress tolerant varieties. This study aims to examine the determinants of farmers' adoption of these technologies and the effects of their adoption on net rice income (NRI) in three provinces as follows: Thai Binh (North), Ha Tinh (Central) and Bac Lieu (South).

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Design/methodology/approach – Determinants of adoption of CSATs and the adoption effects on NRI are analyzed by using a multinomial endogenous switching regression framework.

Findings – The results showed that gender, age, number of family workers, climate-related factors, farm characteristics, distance to markets, access to climate information, confidence on the know-how of extension workers, membership in social/agricultural groups and attitude toward risk were the major factors affecting the decision to adopt CSATs. However, the effects of these factors on the adoption of CSATs varied across three provinces. These technologies when adopted tend to increase NRI but the increase is much greater when these are combined.

Practical implications – It is important to consider first the appropriateness of the CSA packages to the specific conditions of the target areas before they are promoted. It is also necessary to enhance the technical capacity of local extension workers and provide farmers more training on CSATs.

Originality/value – This study is the first attempt to identify key determinants of adoption of CSATs either singly or in combination and the adoption effects on NRI in Vietnam.

Keywords Climate change, Climate-smart agriculture, Adoption, Rice, Farmers, Vietnam

Paper type Research paper

1. Introduction

The recent years have seen a tremendous increase in the volume of literature on climate change and its impacts on agricultural productivity and farmers' livelihood in Southeast Asia. In particular, Vietnam is considered as one of these countries that are most seriously affected by climate change because of its long coastline, geographic location, diverse topography, climate, high concentration of population and economic activity in coastal area (Vien, 2011; World Bank, 2011). The climatic changes that have caused the sea level rise, floods and drought have affected especially Vietnam's rice production sector and its efforts on poverty reduction, food security, employment and export (Trung, 2013).

In Southeast Asia, a key response to these climatic changes was the introduction of climate-smart agriculture (CSA)[1]. The goals for introducing these technologies were to:

- enable these Southeast Asian countries to sustainably increase their incomes and agricultural productivity;
- build both the resilience and the capacity of its agricultural and food systems to adapt to climate change; and
- seek opportunities to reduce and remove greenhouse gas (GHG) to meet their national food security and development goals (Asfaw and Maggio, 2016).

The application of climate-smart agricultural technologies (CSATs) to cope with climate change was viewed as a key strategy for restructuring the agriculture sector program of Vietnam although the current legal framework for integrating CSATs into development policies has been faced with several drawbacks and limitations. The CSA concept is relatively new and not well understood and appreciated by policymakers, scientists and farmers (Nghia *et al.*, 2015).

Farmers have a vast array of alternative technologies that they can use either singly or in combination to deal with various environmental conditions (Dorfman, 1996; Teklewold *et al.*, 2017). Due, however, to differences in cultures, awareness, resource endowments, objectives, preferences and socio-economic backgrounds, farmers differ in their willingness to adopt new technologies (Maguza-Tembo *et al.*, 2017). Farmers may modify or combine different CSATs with other practices and technologies to address their specific conditions and strategy. Therefore, scientists and policymakers should pay more attention to identifying factors that affect farmer's adoption of separate and combined CSATs. The CSATs considered in this study include water-saving techniques (WS) and improved stress tolerant varieties (IS).

Fortunately, the costs and benefits of potential and priority CSATs have been determined in various studies conducted in Vietnam (Nghia *et al.*, 2015). Farmers often build sustainable agricultural production systems that are resilient to different climate-related conditions and other shocks by using a combination of various CSATs (Maguza-Tembo *et al.*, 2017). Unfortunately, of the few studies that have attempted to identify the determinants of farmer adoption of more than one CSAT (Di Falco and Veronesi, 2013; Parvathi and Waibel, 2015; Teklewold *et al.*, 2013, 2017), none of them have been conducted in Vietnam. Thus, it is important to conduct such a study to identify the factors that determine the successful adoption of CSATs in the country. Moreover, there is also a need to test a methodology for identifying key determinants of CSA adoption whether singly or in combination. The findings of this study can guide policymakers in developing plans and programs for disseminating appropriate CSATs and mitigate the detrimental impacts of climate change on the agricultural sector.

2. Selection of study area and sampling selection method

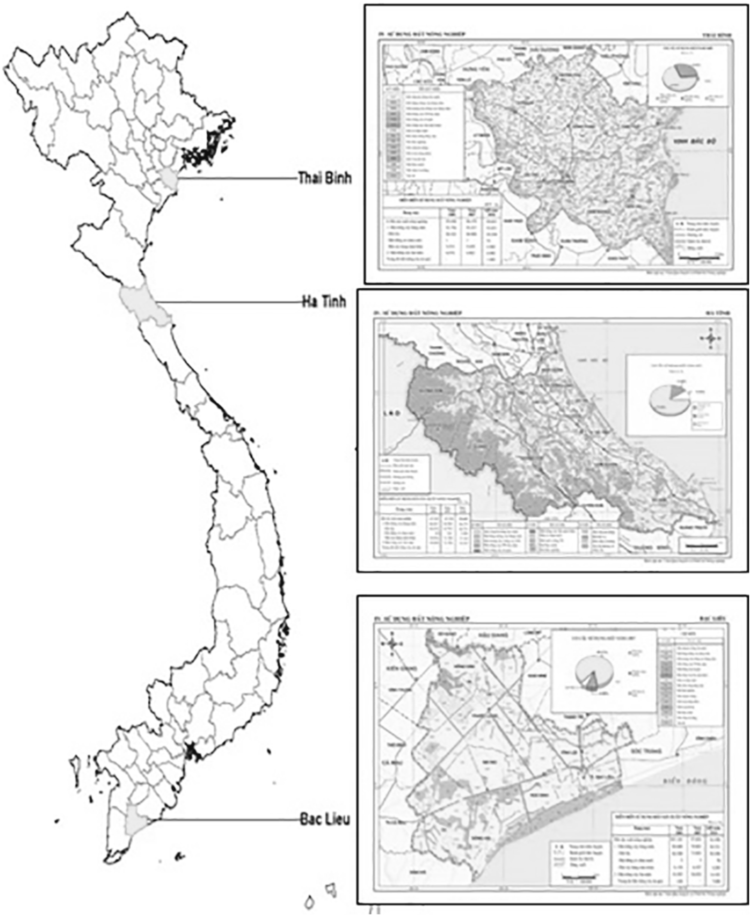
2.1 Selection of study area

The study was conducted in Bac Lieu, Ha Tinh and Thai Binh provinces that are representative of different agro-ecological regions of Mekong River Delta, North Central Coast and Red River Delta, respectively (Figure 1). These provinces have also successfully implemented some of the CSATs such as improved tolerant rice variety, alternate wetting and drying (AWD), a system of rice intensification and others (Dung and Phu, 2016; Sen *et al.*, 2015; Simelton *et al.*, 2017).

Mekong River Delta is one of the major rice-growing regions of the world that is faced with increasing frequency and magnitude of flooding, sea water intrusion with high tide, contaminated soil, sea level rise and seasonal tropical storms (Ninh *et al.*, 2007). In Bac Lieu, a province that is located on the southeast of the Mekong River Delta, the poverty rate is low at 6.4 per cent. It is a relative rather flat area with three ecological zones, namely, brackish water, fresh water and salt-water (General Statistical Office, 2017). The sea level rise, drought and salt-water intrusion in the province adversely affect agriculture and aquaculture production (Phong *et al.*, 2015; Vien, 2011). Three rice crops are grown in the province with both rainfed and irrigated rice production systems (Paris *et al.*, 2010).

The Red River Delta in the North is the second most important agricultural production zones in Vietnam that is critically vulnerable to the impacts of climate change. Thai Binh province, a Coastal Eastern province in the Red River Delta has a fairly flat topographic feature (Dao *et al.*, 2006). Despite the increase in the number of industries because of the market-based economic policy of Vietnam, the agriculture, forestry and aquaculture sectors have still contributing 25-35 per cent of the total provincial value of production over the past 30 years (Thai Binh DONRE (Department of Natural Resources and Environement), 2011). The source of livelihood of about 26 per cent of farmers living along coastal areas is from aquaculture, with most of them also in other traditional livelihood activities. The farmers can grow two crops of rice in the irrigated areas (Paris *et al.*, 2010). The poverty incidence in Thai Binh province at 8.4 per cent in 2017 is one of the lowest in the country (General Statistical Office, 2017).

In the central coast region, including Ha Tinh province, is one of the most vulnerable to typhoons, storm surges, flash floods, drought and saline water intrusion (Chaudhry and Ruysschaert, 2008). About 80 per cent of the province is covered by mountains and a small delta, which is separated by mountains and rivers. Ha Tinh is one of the poorest provinces in the country (General Statistical Office, 2017) and experiencing more variable weather and associated disasters than in the past. Farmers in the province can grow two crops of rice a year in irrigated areas. Then, because of the long coastal line with four estuaries, fishing and aquaculture are also very important to the economy of the province (Thao, 2012).



Source: Invest in Vietnam 2017

Figure 1. Map of Thai Binh, Ha Tinh and Bac Lieu provinces

2.2 Sampling selection method

The primary data were collected in 2016/2017 crop seasons from 579 rice-farming households with 1,747 farming-plots in the three provinces through face-to-face interviews using a household questionnaire (Figure 1). A stratified random sampling procedure was used to select 12 villages of 3 districts in each province. Moreover, villages that do not produce rice were not included. In each province, 200 respondents who were the household heads were randomly selected and evenly distributed into four groups of CSATs combination (Table I).

3. Analytical framework

This study uses a multinomial endogenous switching regression framework to identify the key factors affecting the adoption of CSATs and estimate the effect of adoption on NRI. It can be used for evaluating individual and combined CSA packages (Mansur *et al.*, 2008;

Province	Choice	Package of CSA	WS		IS		Frequency (%)
			WS_0	WS_1	IS_0	IS_1	
Bac Lieu	1	WS_0IS_0	✓		✓		33.2
	2	WS_1IS_0		✓	✓		18.9
	3	WS_0IS_1	✓			✓	24.7
	4	WS_1IS_1		✓		✓	23.2
Ha Tinh	1	WS_0IS_0	✓		✓		25.0
	2	WS_1IS_0		✓	✓		25.5
	3	WS_0IS_1	✓			✓	23.5
	4	WS_1IS_1		✓		✓	26.0
Thai Binh	1	WS_0IS_0	✓		✓		26.9
	2	WS_1IS_0		✓	✓		25.4
	3	WS_0IS_1	✓			✓	29.0
	4	WS_1IS_1		✓		✓	18.7

Note: Subscript is 1 if adopted and 0 otherwise

Table I.
CSA packages used on farming plots

Wu and Babcock, 1998). This framework is composed of two steps. In Step 1, a multinomial adoption selection model is used to identify the key determinants of adoption of CSATs singly and in combination. In Step 2, a counterfactual analysis is used to estimate the average adoption effect of alternative CSA packages on NRI (Teklewold *et al.*, 2017).

3.1 Multinomial adoption selection model

Farmers' adoption choices among WS and IS lead to four possible combinations from which farmers could choose (Table I). Adoption of these combinations may not be random but farmers may endogenously self-select into using or not-using decisions. Thus, decisions are likely to be affected by unobserved characteristics (e.g. expectation of yield gain from adoption, managerial skills, motivation, etc.) that may correlate with the outcome of interest (net farm income, crop yield and cost of material input) (Teklewold *et al.*, 2013, 2017). Farmers will adopt CSATs if the expected utility obtained from the technology is higher than the current technology. Thus, the theory of expected utility maximization is appropriate to use in investigating the farmer's adoption of individual and combined CSATs, as the maximizing solution can be one or multiple (Maguza-Tembo *et al.*, 2017). When the selection is over a large number of exclusive choices, a polychotomous choice framework such as the multinomial logit specification is preferred because of its simplicity. However, the additional hypotheses must be used to embed the multinomial logit into a selection bias correction model (Bourguignon *et al.*, 2007; Parvathi and Waibel, 2015). We assumed that farmers choose to adopt the combination of CSATs to maximize their expected utility (Y_{ij}^*). The latent model (Y_{ij}^*), which describes the behavior of farmer "i" in adopting CSA combination "j" rather than adopting any other alternative combinations can be expressed as following equation (1):

$$Y_{ij}^* = \beta_i X_i + \varepsilon_{ij} \; j = 1 \ldots J \tag{1}$$

Where X_i is a vector of observed exogenous variables that determine the decision to use (household-specific characteristics, economic factors, climate-related shocks, market and institutional factors, farm characteristics and attitudes); and ε_i is a random error term.

The utility to the farmer from choosing a CSA combination is not observed, but the farmer's adoption decision is observable. Let (Y) be an index that denotes the farmer's choice of CSA package. Thus, the farmer will choose a combination of CSATs "j" preferences for adopting any other CSA combinations m if:

$$Y = \begin{cases} 1 \text{ iff } \delta_{i1} < 0 \text{ or } Y^*_{i1} > \max_{m \neq 1}\left(Y^*_{im}\right) \\ . \\ . \qquad\qquad\qquad\qquad \text{for all } m \neq j \\ . \\ j \text{ iff } \delta_{ij} < 0 \text{ or } Y^*_{ij} > \max_{m \neq j}\left(Y^*_{im}\right) \end{cases} \tag{2}$$

Since $\delta_{ij=\max_{m\neq j}\left(Y^*_{im}-Y^*_{ij}\right)^{m\neq j}<0}$

Equation (2) indicates that a combination of CSA "j" will be chosen by farmer "i" to maximize his expected profit and obtain greater expected profit than any other combination $m \neq j$ (Bourguignon *et al.*, 2007; Teklewold *et al.*, 2013).

The (δ_j)s are assumed to be independent and identically Gumbel distributed (the so-called independence of irrelevant alternatives hypothesis) (Bourguignon *et al.*, 2007). The probability that farmer "i" with characteristics X_i choosing a combination of CSATs "j" over other combination of CSATs can be specified by a multinomial logit selection model (McFadden, 1973) as follows:

$$P\left(\delta_{ij} < 0/X_I\right) = \frac{\exp\left(X_i\beta_j\right)}{\sum_{m=1}^{J}\exp(X_i\beta_m)} \tag{3}$$

This expression shows that consistent maximum likelihood estimates of the (δ_j) can be easily obtained given their cumulative and density functions $G(\delta) = \exp(-e^{-\delta})$ and $g(\delta) = \exp(-\delta - e^{-\delta})$, respectively.

3.2 Counterfactual analysis

The average adoption effect of CSA packages on the NRI is estimated in the second stage using a counterfactual analysis. The estimate corrects for the selection bias from the first stage. The relationship between the NRI, (Q_{ij}), and a set of exogenous variables Z (household-specific characteristics, economic factors, climate-related shocks, farm characteristics, market and institutional factors and attitudes) is estimated for each chosen combination of CSATs (Bourguignon *et al.*, 2007). The base category, non-adoption of any CSATs is denoted as j = 1. In the remaining combination (j = 2, 3 and 4) at least one CSAT is adopted. The conditional Ricardian specification for each regime (CSA combination) "j" is given as:

$$\begin{cases} \text{Regime } 1: Q_{i1} = \alpha_1 Z_{i1} + u_{i1} \quad \text{if } Y = 1 \\ . \\ . \qquad\qquad\qquad\qquad j = 2, 3, 4 \\ . \\ \text{Regime } 4: Q_{ij} = \alpha_j Z_{ij} + u_{iJ} \quad \text{if } Y = j \end{cases} \tag{4}$$

Where Q_{ij} is the NRI of the i-th farmer in regime j; Z is as defined above; and u denotes error terms that capture the uncertainty faced by farmers with $E(u_{ij}/X, Z) = 0$ and $Var\ (uij/X, Z) = \sigma_j^2$. If the ε' and u's are not independent, a consistent estimation requires the inclusion of the selection correction terms of the alternative choices in equation (4). Estimates of α in the outcome equation (4) can be obtained by estimating the following selection bias-corrected models (Bourguignon *et al.*, 2007):

$$\begin{cases} \text{Regime } 1: Q_{i1} = \alpha_1 Z_{i1} + \sigma_{1\widehat{\lambda}_{i1}} + e_{i1} \quad \text{if } Y = 1 \\ \quad \vdots \qquad\qquad\qquad\qquad\qquad\qquad\qquad j = 2, 3, 4 \\ \text{Regime } 4: Q_{i4} = \alpha_4 Z_{i4} + \sigma_{4\widehat{\lambda}_{i1}} + e_{i4} \quad \text{if } Y = 4 \end{cases} \tag{5}$$

Here, e is the error term with an expected value of 0, σ is the covariance between ϵ's and u's, λ_{ij} is the inverse Mills ratio computed from the estimated probabilities in equation (3) as follows:

$$\lambda_{ij} = \sum_{m \neq j}^{J} \rho_j \left[\frac{\widehat{P_{im}} \ln\left(\widehat{P_{im}}\right)}{1 - \widehat{P_{im}}} + \ln\left(\widehat{P_{ij}}\right) \right] \tag{6}$$

Here, ρ is the correlation coefficient of ε's and u's are error terms with an expected value of 0. In the multinomial choice setting, there are J-1 selection correction terms, one for each alternative combination of technologies. The error terms in equation (5) are likely to exhibit heteroscedasticity arising from the two-stage estimation procedure. To deal with the heteroscedastic problems, standard errors in equation (5) are bootstrapped (Kassie *et al.*, 2013; Teklewold *et al.*, 2017).

Self-selection models that are estimated in a two-stage procedure have been criticized for being sensitive to misspecification (Wu and Babcock, 1998). The lack of identification is particularly a problem when variables affecting the adoption decisions (X) are the same as those affecting the subsequent outcome equations (Z). For equation (5) to be identified, a simple falsification test with a set of selection instruments (e.g. distance to input and product markets, confidence in the know-how of extension workers, access to climate change information and attitudes) and mean of plot-variant explanatory variables (e.g. soil fertility, slope of plots and land tenure), was used to test the assumption that the instrumental variables affect the choice decision but do not influence the NRI (Di Falco and Veronesi, 2013). In this stage, the least squares regression of NRI was estimated for each combination of CSATs. Then, the unconditional average treatment effect (ATE) and the conditional average treatment effect on treated (ATT) average effects of various combinations of CSATs are derived.

The ATE is estimated to determine whether the adopters of any single CSATs or in combination obtain on average more or less than the value of NRI than non-adopters. From the equation (7), the ATE of combination of technologies (j) versus package (1) is defined as:

$$ATE = E\left(Q_{ij} - Q_{i1}/Z = z_i\right) = Z_i(\alpha_j - \alpha_1) \qquad \text{for } j = 2, 3, 4 \tag{7}$$

However, the ATE does not consider that the difference in the NRI may be caused by observable and unobservable characteristics. Thus, the ATE on the treated or average CSA adoption effect on adopters (ATT) controlling for selection bias that presents the true average adoption effects on NRI was calculated. It shows the counterfactual difference in NRI of adopters if they were non-adopters. ATT is calculated by equation (10) as the difference between equations (8) and (9). Equations (8) represent the actual expected NRI of adopters that were observed in the sample, while equation (9) are their respective counterfactual expected NRI of adopters.

- Adopters with adoption (actual):

$$E\left(Q_{ij}|I = j\right) = Z_{ij}\alpha_j + \sigma_j\lambda_{ij} \quad \text{for } j = 2, 3, 4 \tag{8}$$

- Adopters had they decided not to adopt (counterfactual):

$$E[Q_{i1}|I = j] = Z_{ij}\ \alpha_1 + \sigma_1\lambda_{ij} \quad \text{for } j = 2, 3, 4 \tag{9}$$

- The ATT:

$$ATT = \left[Q_{ij}|I = j\right] - E[Q_{i1}|I = j] = Z_i(\alpha_j - \alpha_1) + \lambda_{ij}(\sigma_j - \sigma_1) \quad \text{for } j = 2, 3, 4 \tag{10}$$

4. Results and discussion

Table I presents the proportion of rice plots cultivated under alternative combinations of WS and IS in three provinces. The combination of these two CSATs provides four mutually exclusive combinations (2^2).

In Vietnam, WS are not applied solely but are integrated with 1Must-5Reduction[2] (1M-5R), large field model[3] (LFM) or system rice intensification[4] (SRI) model. AWD[5] has been developed as a water-saving technique to increase net income and reduce GHG, especially methane, for rice cultivation (Bouman and Tuong, 2001; Lampayan *et al.*, 2015; Rejesus *et al.*, 2011; Wassmann *et al.*, 2010). AWD integrated with 1M-5R and LFM have been implemented in Bac Lieu province, while the WS has been integrated with the SRI model in Ha Tinh and Thai Binh provinces.

Currently, several rice seed companies in Vietnam are providing high quality and high yielding rice seeds that have a high tolerance to extreme weather, pests and disease. However, Vietnam is still highly dependent on imported seeds from India and China and other countries. Although some high quality seeds have been introduced to the local farmers, most farmers in the study sites keep their own seed but do not process them to ensure varietal purity or seed quality. Poor seed quality leads to low vigor and poor growth and is more prone to weed, and insect infestation and diseases. For the purpose of this study, therefore, farmers are considered as adopters if they use pure seeds of high quality that are very tolerant of extreme weather, pests and diseases.

A review of the literature shows that there are many categories for grouping the factors affecting farmer's adoption of new technologies (Kassie *et al.*, 2013; Maguza-Tembo *et al.*, 2017; Mwangi and Kariuki, 2015; Rejesus *et al.*, 2011; Teklewold *et al.*, 2013, 2017) based on the current technologies being investigated, the location and the researcher's reference or even suitability to clients' needs (Bonabana-Wabbi, 2002). In this study, the categorization is based on the CSATs being investigated and literature reviews. These factors include household-specific characteristics (gender, age, education level of respondents, number of family workers and experience in rice cultivation) (Bonabana-Wabbi, 2002; Chander and Thangavelu, 2004;

Lavison, 2013; Leavy and Smith, 2010; Mignouna *et al.*, 2011; Obisesan, 2014; Omonona *et al.*, 2006; Teklewold *et al.*, 2017); economic factors (rice income, off-farm income, tropical livestock unit and area of rice farms) (Ellis and Freeman, 2004; Gabre-Madhin and Haggblade, 2004; Harper *et al.*, 1990; Katengeza *et al.*, 2012; Lowenberg-DeBoer, 2000; Maguza-Tembo *et al.*, 2017; Mignouna *et al.*, 2011; Parvathi and Waibel, 2015; Reardon *et al.*, 2007; Uaiene *et al.*, 2009; Yaron *et al.*, 1992); market factors (distance from household to input and product markets) (Jansen *et al.*, 2006; Wollni *et al.*, 2010); institutional factors (access to agricultural extension and credit, access to climate information, confidence on the know-how of extension workers and membership in social/agricultural groups) (Maguza-Tembo *et al.*, 2017; Mignouna *et al.*, 2011; Mwangi and Kariuki, 2015; Teklewold *et al.*, 2017); climate-related shocks (rainfall satisfaction index, waterlogging, drought stress, and pest and disease stress) (Jansen *et al.*, 2006; Kassie *et al.*, 2013; Teklewold *et al.*, 2013); farm characteristics (land tenure, slope of plots and soil fertility); and attitudes (self-assessments of likelihood of willingness to try new technologies and attitude toward risk) (Arslan *et al.*, 2017; Besley, 1995; Kassie *et al.*, 2013; Teklewold *et al.*, 2013, 2017). The description and descriptive statistics of these explanatory variables are not reported to conserve space but are available upon request from the authors.

Farmers in Bac Lieu province have on average significantly higher income from their rice production (86.7 million dong/year) than in other provinces (24.3 and 11.3 million dong/year for Ha Tinh and Thai Binh province, respectively) while their off-farm income is relatively lower (23.8, 32.0 and 34.1 million dong/year for Bac Lieu, Ha Tinh and Thai Binh provinces, respectively). The reason is that rice production is the main income source of farmers in Bac lieu province (i.e. rice production occupied 78 per cent to total household income) while the households in Ha Tinh and Thai Binh provinces derive most of their income from other off-farm and non-farm income activities to compensate for the low income from rice production (i.e. rice production contributed 24 and 20 per cent to total household income in Ha Tinh and Thai Binh provinces, respectively). A comparison of farm households by the level of household income shows that the higher-income households were more likely to adopt CSATs in all provinces.

4.1 Determinants of adoption of climate-smart agricultural technologies

Table II presents results of the multinomial logit selection model that compared all factors affecting the adoption of CSATs for alternative combinations of CSATs in Bac Lieu, Ha Tinh and Thai Binh provinces. The result shows that there is good correlation between unobserved household fixed effect and observed covariates in these models. The estimated results show that the models fit data reasonably well. It also shows the relatively different results in the adoption different packages of CSATs in each province and among the three provinces.

The positive relationship of gender within a selection of CSATs in Bac Lieu province and negative in other provinces means that women in Ha Tinh and Thai Binh provinces are more likely to adopt CSATs in comparison to the men. This is because Ha Tinh and Thai Binh provinces have smaller plots of rice fields[6] compared to Bac Lieu province. Therefore, most farmers in Ha Tinh and Thai Binh provinces cultivate rice for home consumption rather than for sale. Because of the small farm sizes and limited income from rice farming, 16.8 per cent of male household heads[7] from Ha Tinh and 22.6 per cent from Thai Binh provinces have left and sought non-farm work in the cities or other countries. The absence of the male household heads who seek non-farm work may increase the tasks and farm management responsibilities of the wives or women (Paris *et al.*, 2009). As a consequence, the women left behind gain more experience and knowledge about managing their rice farms so that they are now more likely to adopt CSATs. These results corroborated the

Table II. Summary of the key determinants of adoption of CSATs

Determinants of CSA adoption	Bac Lieu WS_1IS_0	Bac Lieu WS_0IS_1	Bac Lieu WS_1IS_1	Ha Tinh WS_1IS_0	Ha Tinh WS_0IS_1	Ha Tinh WS_1IS_1	Thai Binh WS_1IS_0	Thai Binh WS_0IS_1	Thai Binh WS_1IS_1
Gender (1 = male, 0 = female)	3.30*	1.29*	0.78	−1.43	−1.57*	−1.08	−1.80**	−1.31**	−0.60
Age (yrs)	−0.14*	−0.09**	−0.04	0.09	0.19***	0.08	0.01	−0.06	−0.21***
Education (yrs)	0.18	0.04	0.10	0.08	−0.14	0.06	0.07	−0.16	0.07
Experience in rice cultivation (yrs)	0.10	0.06	0.03	−0.02	−0.06	0.04	0.001	0.009	0.17***
No. of family workers (people)	−1.91**	0.21	−0.04	−1.73**	−0.60	−2.16**	−0.89	−0.63	−0.50
Rice area (ha)	−2.70***	−2.00***	−1.65**	9.54***	11.61***	12.95***	−5.73**	−2.18	−0.54
Rice income (million dong/year)	0.05***	0.04***	0.03***	0.003	0.03	0.01	0.13***	0.06**	0.10***
Off-farm income (million dong/year)	0.01	−0.02	0.004	−0.01	0.001	−0.01	−0.009	−0.03***	−0.06***
Tropical livestock unit	0.34	−0.29	−0.09	0.54**	0.57***	0.49**	−0.60**	−0.043	−0.30
Rainfall index (1 = best, 0 = worst)	−4.81**	7.19***	2.48*	−1.27	2.44**	2.66	2.03	3.24*	6.54***
Pest and disease (1 = yes, 0 = otherwise)	0.76	−1.84*	0.96	0.87	0.54	2.12**	−1.39	−0.21	14.60***
Waterlogging (1 = yes, 0 = otherwise)	1.39	2.54***	0.37	−0.52	0.26	−1.75	2.18***	0.89	1.69**
Drought (1 = yes, 0 = otherwise)	6.06***	8.13***	5.20***	2.59***	1.27	1.98**	1.62	1.91**	0.80
Land tenure (1 = own the plot, 0 = otherwise)	3.74	−1.201	12.08***	5.28***	3.27*	2.17	1.26	−1.05	0.50
Soil fertility (3 = highly fertile, 2 = moderately fertile and 1 = poorly fertile)	−2.35***	−1.68***	−2.20***	2.91**	0.85	3.73***	3.64***	3.65***	2.35**
Slope of plots (1 = deep, 2 = medium and 3 = flat)	−0.85	6.09***	5.25***	−1.31	−2.09	−0.97	1.62***	−0.11	1.27
Distance to product market (km)	−1.51	−4.22***	−2.86**	−0.91	−1.30**	−0.29	1.58	−0.59	2.04*
Distance to input market (km)	−0.18	−0.64***	−0.22	−0.86***	−0.32*	−0.81***	1.51***	0.60	2.04***
Access to extension (1 = yes, 0 = otherwise)	0.90	0.28	0.67	0.71	−0.97	0.59	1.36	1.14	−0.88
Access to credit (1 = yes, 0 = otherwise)	0.42	2.38***	1.45*	0.36	0.34	0.03	−0.79	−0.25	−0.97
Access to CC information (1 = yes, 0 = otherwise)	−0.21	0.77	1.04	3.60***	0.90	1.17	0.17	2.83**	2.34
Confidence in know-how of extension workers (scale 1-5 where 5 signifies high confidence)	1.27	1.60**	0.49	0.57**	−0.09***	0.45	1.44**	0.99**	0.50
Membership in social/agricultural groups (groups)	−1.83**	−0.30	−0.37	0.21	0.18	−0.07	1.29***	1.54***	1.55**
Attitude toward risk (1 = farmers is risk loving, 0 = otherwise)	3.08**	0.58	0.02	2.46***	1.65**	1.82**	0.76	3.70**	0.58
Self-assessments of innovative index	−0.59	0.66	1.76***	−0.16	−0.63	−1.19	−0.38	−0.62	−0.32
Joint significance of selection instruments χ^2 (5)	9.26*	19.43***	6.39	27.54***	16.98***	20.58***	12.32**	12.18**	16.12***
Joint significance of plot varying covariates χ^2 (3)	9.77**	17.84***	10.81**	15.98***	3.63	19.00***	21.12***	12.70***	13.26***
	Number of observations = 190; Wald χ^2 (84) = 1,145.35; $p > \chi^2 = 0.0000$			Number of observations = 196; Wald χ^2 (84) = 197.32; $p > \chi^2 = 0.0000$			Number of observations = 193; Wald χ^2 (84) = 900.74; Prob > $\chi^2 = 0.0000$		

Notes: *, **; *** indicate statistical significance at the 10, 5 and 1% level, respectively. The subscript is 1 if adopted and 0 otherwise findings of Nhemachena and Hassan (2007), which revealed that female-headed households tend to adopt climate change adaption methods in farming. The situation in Bac Lieu province is a bit different given the larger farm sizes and favorable biophysical conditions for rice production. The male household heads are not forced to leave and take non-farm jobs, and thus, are the ones managing their own rice farms, which are the major source of income. Only 5.5 per cent of the male household heads leave in Bac Lieu province to work in other provinces.

The age of farmers was also found to have different influences on the adoption decision of CSATs in the three provinces. In Ha Tinh province, the older farmers are more likely to adopt CSATs. This finding is similar to those of Mignouna *et al.* (2011) and Kariyasa and Dewi (2013), who argued that older farmers have gained knowledge and experience over time from coping with climate-related shocks and are better at evaluating technology information than younger farmers. In contrast, the younger farmers in Bac Lieu and Thai Binh provinces are more likely to adopt CSATs than older farmers. This corroborated the findings of Adesina and Zinnah (1993) and Leavy and Smith (2010), who found that older farmers were more risk averse and less likely to make long-term investments in the farm than younger farmers.

It is interesting to note that the availability of family labor has a significant effect on the adoption of WS for rice production (WS_1IS_0) in Bac Lieu and Ha Tinh provinces in contrast to that of Thai Binh province where it is not considered important. The result, however, is inconsistent with the findings of Bonabana-Wabbi (2002), Mignouna *et al.* (2011) and Teklewold *et al.* (2013), whose findings show that farmers with larger households are more willing to adopt CSATs especially those new technologies, which are more labor intensive. Income from rice farming also has a positive effect on the decision of farmers to adopt CSATs in the three provinces, as it provides them the necessary capital for investment in the CSATs (Katengeza *et al.*, 2012; Maguza-Tembo *et al.*, 2017).

Most of the climate-related factors are found to have a significant impact on CSA adoption. CSA packages are more likely to be adopted in drought and waterlogged plots. Farmers in different provinces have also different strategies to cope with pest and disease infestation. In Bac Lieu province, farmers are not likely to apply the IS (WS_0S_1) on the plot areas that experienced the pest and disease infestation. However, WS in combination with IS (WS_1IS_1) is more likely to be adopted on plots previously affected by pests and disease in Ha Tinh and Thai Binh provinces. This result shows that the adoption of different packages of CSATs is very site-specific, which considers the unique characteristics that influence the appropriateness of the technology.

Land tenure and slope of plots have positive effects on the use of alternative CSA packages. Farmers are more likely to adopt CSATs (WS_1S_1) if they own the land and the topography is flat as shown in the case of Bac Lieu province. These results support the previous works of Kassie and Holden (2007) and Maguza-Tembo *et al.* (2017), who found that tenants are less likely to apply new technologies on rented plots because of the absence of security of tenure in the farm. In the same way, the quality of the soil and the weather conditions affect the farmers' adoption decisions. For instance, the biophysical conditions in the Bac Lieu province is very favorable for rice production, as the soil is still very fertile. Thus, farmers would tend to adopt technology only if the soil is poor or moderately fertile. In contrast, the soil quality in the Central and the Northern regions of Vietnam such as Ha Tinh and Thai Binh provinces that are more exposed to extreme weather conditions is quite poor. Thus, farmers in Ha Tinh and Thai Binh provinces only tend to apply CSATs on plots that are very fertile to reduce the risk of yield loss.

The distance to markets has a negative effect on the CSA decisions of farmers in both Bac Lieu and Ha Tinh provinces. Local farmers are likely to apply the new technologies if their land/plot is close to the markets for their farm produce and source of farm inputs and services. Also, institutional factors such as access to climate information, confidence in know-how of extension workers and membership in social/agricultural groups have a positive impact on the adoption of different packages of CSATs that confirm the finding in the studies of Mignouna *et al.* (2011), Mwangi and Kariuki (2015), Teklewold *et al.* (2017) and Maguza-Tembo *et al.* (2017).

An interesting finding is that more than access to extension services, confidence in the know-how of extension workers is a more important factor influencing farmers to adopt of CSATs. This result supports the finding of Teklewold *et al.* (2017), who found that it is not the extension contact *per se* that influences the adoption decision, but rather the quality of the extension workers. This is probably because the package of technologies that combine the WS and IS is relatively knowledge-intensive and requires considerable managerial skills. All these results emphasize the importance of quality of extension services, the provision of climate information to farmers and the role of social organizations in enhancing and disseminating the CSATs. Farmers' attitude toward risk is also found to have a positive influence on the uptake of CSATs. Thus, providing evidence-based critical climate change information and knowledge of CSATs to build resilience and reduce uncertainty to farmers is important.

4.2 Effects of adoption of climate-smart agricultural technologies on net rice income

The least squares regression of NRI for each combination of CSATs is estimated in the second stage while correcting the selection bias in the first stage[8]. Generally, there is a statistically significant correlation between the number of explanatory variables and NRI. There are substantial differences between the NRI equations' coefficients among different packages of CSATs. This illustrates the heterogeneity in the sample in relation to NRI. Also, most selection correction terms are not statistically significant indicating that adoption of WS and IS will have the same effect on NRI impact of non-adopters, if they choose to apply these CSATs as those farmers who have already implemented them.

Table III presents the unconditional average effects (ATE) of the adoption of different combinations of WS and IS in the three provinces. The estimates of ATE indicate that adopters of any CSA package either in isolation or in combination earn more NRI, on average than non-adopters. Except for the case of Bac Lieu province, the *t*-test result shows that there is no significant difference between adoption of WS and IS package (WS_1IS_1) and non-adoption of any CSA (WS_0IS_0).

	Bac Lieu		Ha Tinh		Thai Binh	
CSA packages	NRI	ATE	NRI	ATE	NRI	ATE
WS_0IS_0	35.8 (12.84)	–	22.08 (0.80)	–	31.95 (1.02)	–
WS_1IS_0	42.7 (39.42)	6.90** (3.01)	36.10 (1.31)	14.00*** (1.53)	37.88 (1.31)	5.93*** (1.67)
WS_0IS_1	54.4 (20.67)	18.57*** (1.77)	28.84 (0.85)	6.76*** (1.17)	39.60 (0.94)	7.65*** (1.39)
WS_1IS_1	31.0 (61.05)	−4.80 (4.53)	27.31 (1.05)	5.23*** (1.32)	46.90 (1.56)	14.95*** (1.87)

Notes: Figures in parentheses are standard errors; **; *** indicate statistical significance at the 5 and 1% level, respectively. The subscript is 1 if adopted and 0 otherwise

Table III. The unconditional average effect of the adoption of CSATs on NRI (million dong/ha/year)

The conclusion, however, from this simple comparison is misleading because it does not take into account the observed and unobserved factors that may affect the NRI. The naive comparison by using ATE would lead to the conclusion that farm households in Ha Tinh province that adopted IS (WS_0IS_1) earned about 14 million dong/ha/year more than farm households that did not adopt. Thus, the conditional average effects (ATT) were estimated to show the true average adoption effects on NRI given different packages of CSA in isolation or combination.

The estimated results of ATT (Column C) is presented in Table IV by comparing the Columns A and B. In Bac Lieu province, the results show that the adoption of WS (WS_1IS_0) singly or a combination of IS (WS_1IS_1) provide higher NRI compared with non-adoption (WS_0IS_0). Also, the results show that there is no difference in NRI between the adoption of IS (WS_0IS_1) and non-adoption (WS_0IS_0). This could be explained by the fact that majority of local farmers suffered from yield losses due to rice lodging that was caused by the occurrence of unanticipated cyclones during the harvesting time. However, the largest income effect (36.75 million dong/ha/year) was obtained from applying IS joint with WS (WS_1IS_1).

In Ha Tinh and Thai Binh provinces, the ATT results show that the adoption of any CSATs, whether singly or in combination, provides higher NRI compared with non-adoption. However, the effect of IS on NRI is highly significant at the 1 per cent statistical level when combined with WS. For Ha Tinh province, the effect of WS and IS package (WS_1IS_1) is equal to 15.0 million dong/ha/year while the impact of WS (WS_1IS_0) and IS in isolation (WS_0IS_1) are 9.12 and 10.37 million dong/ha in 2017, respectively. Similarly, the higher NRI (11.36 million dong/ha/year) was obtained from the adoption of WS in combination with the IS in Thai Binh province. This is a clear indication of complementarity between the two CSATs.

5. Conclusions and recommendations

This study provides an analysis of determinants of adoption of CSATs and adoption effects on NRI in Thai Binh, Ha Tinh and Bac Lieu provinces. The findings indicate that the current choice of different packages of CSATs in three provinces are significantly affected by gender, age, number of family workers, climate-related factors, farm characteristics, distance to markets, institutional factors such as access to climate information, confidence on the know-how of extension workers, membership in social/agricultural groups and attitude toward risk although in general these factors are found to have different effects on the adoption decision of CSATs among the three provinces.

In particular, the findings of the study are as follows:

- Gender has a positive effect on the adoption of WS and IS in Bac Lieu province, but a negative effect on adoption of these CSATs in other provinces;
- The older farmers are more willing to adopt CSATs in Ha Tinh province, in contrast to Bac Lieu and Thai Binh provinces where the younger farmers are more willing to adopt these CSATs;
- The number of family workers is negatively related to the likelihood of adopting WS in Bac Lieu and Ha Tinh provinces in contrast to the Thai Binh province where it is not an important consideration;
- CSATs are more likely to be adopted in rice plots that experienced a lack of water and waterlogging than those that did not;

Table IV. The conditional average effect of the adoption of CSATs on NRI of adopter (million dong/ha/year)

	Bac Lieu			Ha Tinh			Thai Binh		
	(A)	(B)	(C)	(A)	(B)	(C)	(A)	(B)	(C)
Out-come	Actual NRI if farm HHs did adopt	Counterfactual NRI if farm HHs did not adopt	ATT	Actual NRI if farm HHs did adopt	Counterfactual NRI HHs did not adopt	ATT	Actual NRI if farm HHs did adopt	Counterfactual NRI if farm HHs did not adopt	ATT
WS_1IS_0	49.88 (3.28)	42.71 (6.48)	7.18** (9.05)	29.82 (1.69)	20.70 (1.48)	9.12*** (2.25)	38.56 (1.47)	32.97 (1.71)	5.59** (2.26)
WS_0IS_1	52.32 (2.06)	57.40 (2.88)	−5.07 (3.77)	31.17 (1.58)	20.77 (1.92)	10.40*** (2.49)	38.04 (1.41)	35.15 (2.09)	2.89** (2.52)
WS_1IS_1	48.11 (2.04)	11.35 (10.71)	36.75*** (12.81)	34.33 (1.14)	19.33 (1.66)	15.00*** (2.02)	37.57 (2.29)	26.21 (3.03)	11.36*** (3.79)

Notes: Figures in parentheses are standard errors; **; *** indicate statistical significance at the 5 and 1% level, respectively. The subscript is 1 if adopted and 0 otherwise; HHs = Households

- In Bac Lieu province, farmers are more likely to plant traditional varieties, instead of IS, if pests and disease affect their rice plots while in the other provinces, they would use IS combined with the WS;
- Security of tenure affects farmers' decision to adopt CSATs, that is, they are more likely to use them on their owned land rather than on rented or borrowed land;
- In Bac Lieu province, all packages of CSATs are more likely to be adopted by farmers in plots or farms with poor and moderate fertility while in other provinces, these are more likely to be adopted either singly or in combination where the soil is fertile;
- Distance to markets is negatively related to the adoption of CSATs, but positively related to access to climate information, confidence on the know-how of extension workers and membership in social/agricultural groups;
- Farmers who are more willing to take risks are more likely to adopt CSA; and
- The NRI is more likely to increase with the adoption of WS and IS, whether adopted singly or in combination with other technologies. However, the largest increase in income in all provinces under study is from the adoption of IS with WS.

The implications of these findings are as follows:

- It is important to take into consideration the key determinants affecting the adoption of the CSATs identified in this study in developing the plans and strategies for disseminating of these CSATs at both local and national level;
- The area-specific conditions in each province should be properly evaluated to determine the appropriateness of promoting CSA packages;
- Institute appropriate policies to provide security of tenure and facilitate the operation of the land rental markets;
- Ensure that extension workers have the necessary technical know-how to inspire the confidence of farmers on their technical capability and recommendations; and
- Finally, provide more training to farmers through field research/experiments and evidence-based critical climate change information to build resilience and increase knowledge of CSATs.

Notes

1. CSA is neither a specific technology, nor a set of practices, nor a new agricultural system that can be universally applied. It is an approach to developing the technical, policy, and investment conditions to achieve sustainable agricultural development for food security under climate change; a way to guide the needed changes of agricultural systems, given the necessity to jointly address food security and climate change. It requires site-specific assessments to identify suitable agricultural technologies and practices (World Bank, FAO and IFAD, 2015).
2. One must" recommends that farmers must use certified seeds; "five reductions" include reducing seed rate, fertilizer, pesticide, water and post-harvest loss (Chi *et al.*, 2013).
3. LFM is a type of production organization, in which enterprises or cooperatives establish a cooperative relationship with farmers to apply a uniform production system by providing production inputs and/or buying outputs from producers (Thang *et al.*, 2017).
4. Five technical principles of SRI: use healthy young seedlings, transplant single seedlings, weed early, manage water and aerate soil and apply manure and compost (World Bank, FAO and IFAD, 2015).

5. AWD irrigation is a field water management technique developed by IRRI to improve water-use efficiency in rice production. Most of the AWD field experiments that have been tested successfully in non-saline soils have significantly reduced water use and increased farm profitability. Total water inputs decreased by 15-30% without a significant impact on yield. In these studies, it was concluded that rice yield remained satisfactory if irrigation was re-supplied when the soil water tension was around −10 kPa or when the perched water table reached a threshold value of −15 cm below the soil surface (Lampayan *et al.*, 2015; Richards and Sander, 2014).
6. Based on the sample respondents, mean of rice plot area of Bac Lieu, Ha Tinh and Thai Binh provinces are 1.40, 0.33 and 0.18 ha of land, respectively.
7. Household heads are who actually make the major decisions in the household.
8. The second stage regression was estimated by using the Stata selmlog command. The results will be provided on request to conserve space.

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Corresponding author
Nhat Lam Duyen Tran can be contacted at: trannhatlamduyen@gmail.com

Climate change impacts on cereal crops production in Pakistan

Evidence from cointegration analysis

Faiza Ahsan
Sichuan Agricultural University – Chengdu Campus, Chengdu, China

Abbas Ali Chandio
College of Economics, Sichuan Agricultural University – Chengdu Campus, Chengdu, China, and

Wang Fang
Sichuan Agricultural University – Chengdu Campus, Chengdu, China

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Abstract

Purpose – This paper aims to examine the effects of CO_2 emissions, energy consumption, cultivated area and the labour force on the production of cereal crops in Pakistan from the period 1971-2014.

Design/methodology/approach – The study used the Johansen cointegration test, the autoregressive distributed lag (ARDL) approach and Granger causality test to estimate the long-run cointegration and direction of the relationship between the dependent and independent variables.

Findings – The outcomes of the Johansen cointegration test confirmed the existence of a long-term cointegrating relationship between the production of cereal crops, CO_2 emissions, energy consumption, cultivated area and the labour force. The results of the long-run coefficients of CO_2 emissions, energy consumption, cultivated area and labour force have a positive impact on cereal crops production. The long-run relationships reveal that a 1 per cent increase in CO_2 emissions, energy consumption, cultivated area and labour force will increase cereal crops production by 0.20, 0.11, 0.56 and 0.74 per cent, respectively. Moreover, the findings show that there is a bidirectional causality running from CO_2 emissions and cultivated area to cereal crops production. Moreover, there is a unidirectional causality running from energy consumption to cereal crops production.

Originality/value – The present study also fills the literature gap for applying the ARDL procedure to examine this relevant issue for Pakistan.

Keywords Pakistan, Cointegration, Energy consumption, CO_2 emissions, Cereal production

Paper type Research paper

1. Introduction

The agricultural sector plays a significant role for the path of national economic development. Agriculture exists worldwide and allows farmers to grow and improve their crops with available inputs (Banerjee and Adenaeuer, 2014). This sector plays a significant role and contributes to the

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economic prosperity of advanced countries, and its role in developing countries has its own role and importance. However, most crops are dependent on the prevailing climate in a specific region or area (Gornall *et al.*, 2010). Weather and climate are key factors that influence agricultural productivity. Global climate change has become a serious threat to activities in the agriculture sector and has become critical for the sustainable development of any nation (Howden *et al.*, 2007). Therefore, the main climate change impact is on the production of the agricultural sector because of the changes in temperatures, rain patterns, floods and famines, and it has negative effects on the land and water resources (Ali *et al.*, 2017). Developing countries (such as in Africa and Asia) have progressed in their technology, and this progress is considered to have decreased the effects of climate change on production from the agricultural sector. Studies have shown that there are substantial effects from changing rainfall patterns and from increasing temperatures on food production (Zhao *et al.*, 2017). Climate change is considered to be a global issue, but developing countries are more widely affected; the reason is their higher vulnerability to climate change and their lower ability to mitigate climate change effects (Ali *et al.*, 2017; Rauf *et al.*, 2018). Developing countries, including Pakistan, are mostly agriculture-based nations, so they incur major effects on their economies due to their direct exposure to nature. The climate of Pakistan is suitable for the production of various crops, such as wheat, cotton, maize, rice and sugarcane (Dharmasiri, 2012), but above all, wheat is the main crop in this region because of its high consumption, demand and most importantly, the available climatic conditions (Curtis and Halford, 2014). Most of the studies related to food availability emphasize the growth of agricultural output (Swaminathan and Bhavani, 2013). Climate factors (long-term) and weather (short-term) influence agricultural productivity (Shannon and Motha, 2015). For example, there was a weak monsoon system in 1987 that caused high levels of crop yield reductions in Pakistan, India and Bangladesh, contributing to a need for wheat imports by India and Pakistan (Gonzalez-Garcia and Gaytan, 2006). Countries in tropical and sub-tropical regions are most likely to be more vulnerable to warming due to additional increases in temperature, which will stress the balance of marginal water and damage agricultural sector crops. Climate change increases the vulnerability of the agricultural sector in the form of floods and famines, causing socio-economic losses for the country (Ali *et al.*, 2017). The research implies that the production of food at the domestic level must increase to reach a state of self-sufficiency in Pakistan (Clapp, 2017). Climate effects can change the time to maturity that a crop requires (Hatfield and Prueger, 2015). Soil fertility can be affected by erosional processes, frequent pest attacks can intensify, a number of products for the crops cultivated can decrease on a yearly basis, harvest periods can increase and water availability for irrigation can decrease due to climate changes (Bhardwaj *et al.*, 2018). Adams *et al.* (1998) stated that the major determinants of agricultural productivity are climatic aspects such as rains, high temperatures and occurrences of extreme events such as floods, droughts and windstorms, which have direct impacts on livestock and crops yield. Advanced research during the past 20 years by the Centre of International Maize and Wheat Improvement (CIMMYT) has explained that wheat production in warmer areas is scientifically feasible (Wang *et al.*, 2016). Wheat has been the number one domesticated food crop and was a basic staple item for European, North Africa and West Asia populations 8,000 years ago, (Fuller, 2007). Today, wheat crop is produced and harvested on more land area than any other crops and continues to the greatest significant human grain source; wheat production leads to other crops, such as potatoes, maize and rice (Shewry and Hey, 2015). The latest research anticipates that wheat production in South Asia will decrease by 50 per cent in 2050, almost equal to the 7 per cent of the global production of this crop (Jaggard, Qi, and Ober, 2010). Wheat crop has improved over a wide range of moisture conditions from xerophytic to littoral (Monneveux *et al.*, 2012). Optimal production needs a sustainable source of moisture during the growing season; however, excess rainfall can lead to yield losses due to root problems and diseases (Hatfield and Prueger, 2015). Cultivars with widely differing pedigrees are grown across wide climate and soil conditions and show wide changes in their features (Lammerts van Bueren *et al.*, 2011). However, wheat is being cultivated across the world at any time of the year, and cultivation in the temperate regions begins between April and September in the northern hemisphere and between October and January in the southern hemisphere (Percival, 1921). Therefore, the main aim of this research is to examine the long-run impacts of climate change, energy consumption, cultivated area and the agricultural labour force on cereal crops production in Pakistan for the period from 1971 to 2014 by use of the autoregressive distributed lag (ARDL) bounds testing method.

2. Data source and econometric methodology

2.1 Data source

The data for cereal crops production (kg per hectare), land under cereal production (hectares), energy consumption (kWh per capita) and rural population (million) have been taken from the World Development Indicators (WDI, 2016).

2.2 Econometric methodology

The present study aims to examine the linkages between carbon dioxide emissions, energy usage, cultivated area and cereal crops production using the ARDL cointegration approach. The association is expressed as follows:

$$LogCP_t = \alpha_0 + \alpha_1 LogCO2_t + \alpha_2 LogEN_t + \alpha_3 LogCA_t + \alpha_4 LogLF_t + \varepsilon_t \tag{1}$$

Equation (1) represents the effects of carbon dioxide emissions, energy consumption, cultivated area and rural population, used as a proxy for agricultural labour force, on cereal crops production. CP refers to cereal crops production, CO_2 refers to carbon dioxide emissions, EN stands for energy consumption, CA means cultivated area and LF means labour force, t represents the period and ε stands for the stochastic terms.

2.2.1 Autoregressive distributed lag bounds testing approach. The ARDL approach to cointegration was introduced by Pesaran and Pesaran (1997), Pesaran and Shin (1998) and Pesaran *et al.* (2000, 2001). This approach was applied without the restricted model of vector error correction to inspect the long-run linkages between changing weather conditions, energy consumption and the production of cereal crop. An economic study analysis posits that there are long-run links among the variables under consideration as required by the model. This notion means that long-run linkage features are integral to the method. In economic terms, the variance and means are constant and do not depend on time. Most empirical studies, however, have shown that the constancy of variances and means is not satisfied when considering the variables of time series. To resolve this problem, most cointegration techniques are not applied, interpreted or estimated accurately. The ARDL approach is better estimated for small-sample data properties. The ARDL model is set up to estimate as follows:

$$\begin{aligned}\Delta LnCP_t = {} & \Psi_0 + \Psi_1 \sum_{i-1}^{p} \Delta lnCP_{t-1} + \Psi_2 \sum_{i-1}^{p} \Delta lnCO2_{t-1} + \Psi_3 \sum_{i-1}^{p} \Delta lnEC_{t-1} \\ & + \Psi_4 \sum_{i-1}^{p} \Delta lnCA_{t-1} + \Psi_5 \sum_{i-1}^{p} \Delta lnLF_{t-1} + \delta_1 lnCP_{t-1} + \delta_2 lnCO2_{t-1} \\ & + \delta_3 lnEC_{t-1} + \delta_4 lnCA_{t-1} + \delta_5 lnLF_{t-1} + \varepsilon_t,\end{aligned} \tag{2}$$

where Δ denotes the difference operator, Ψ denotes the short-run coefficients, Δ denotes the long-run coefficients and $\mathcal{E}_t$ represents the error term. The co-movement of long-run among the variables of interest is determined on the basis of the estimated F-statistic. The ARDL cointegration technique does not require pre-tests for unit roots, unlike other techniques. Consequently, the ARDL cointegration approach is preferable when dealing with variables which are integrated in different orders, and the combination of both is rigorous when there is only one long-run linkage between the small sample-sized underlying variables. The long-run linkage of the underlying variables is identified with the help of the F-statistic (Wald test). Long-run relationships in the series are considered to be estimated in this approach when the F-statistic surpasses the band of critical value. The main advantage of this method lies in its cointegrating vector identification where there are various cointegrating vectors. If a long-run cointegration between CO_2, energy consumption, cultivated area, labour force and cereal crops production is found, the long-run relationship coefficients are estimated with the following equation:

$$LnCP_t = \xi_0 + \xi_1 \sum_{i-1}^{p} lnCP_{t-1} + \xi_2 \sum_{i-1}^{p} lnCO2_{t-1} + \xi_3 \sum_{i-1}^{p} lnEC_{t-1} + \xi_4 \sum_{i-1}^{p} lnCA_{t-1} + \xi_5 \sum_{i-1}^{p} lnLF_{t-1} + \varepsilon_t. \quad (3)$$

If a long-run association amongst the CO_2, consumption of energy, cultivated area, labour force and cereal crops production is found, then the short-run association coefficients are estimated by the following equation:

$$\Delta LnCP_t = \phi_0 + \phi_1 \sum_{i-1}^{p} \Delta lnCP_{t-1} + \phi_2 \sum_{i-1}^{p} \Delta lnCO2_{t-1} + \phi_3 \sum_{i-1}^{p} \Delta lnEC_{t-1} + \phi_4 \sum_{i-1}^{p} \Delta lnCA_{t-1} + \phi_5 \sum_{i-1}^{p} \Delta lnLF_{t-1} + \theta ECT_{t-1} + \varepsilon_t. \quad (4)$$

The method of error correction explains the adjustment of speed required to restore the equilibrium of the long-run following a short-run shock. Θ shows the computed error correction coefficient term for the approach that shows a speed modification.

3. Results and discussion

3.1 Descriptive summary, correlation and stationarity analysis

Table I explains the initial descriptive data statistics used for the estimation; the Jarque–Bera test suggests that all variables are normally distributed. Additionally, the estimated outcomes of the correlation analysis in Table I indicate that CO_2 emissions, energy consumption, cultivated area and the labour force are significantly and positively linked with cereal crops production. We tested if the selected studied variables were stationary at level/first difference. In the process, this study used the augmented Dickey–Fuller (ADF) test (Dickey and Fuller, 1979), the Phillips–Perron (PP) test (Phillips and Perron, 1988) and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test (Kwiatkowski *et al.*, 1992) as unit root tests to confirm whether the studied variables were stationary or not. The estimated empirical outcomes of the ADF, PP and KPSS unit root tests are described in Table II,

	lnCP	$lnCO_2$	lnEC	lnCA	lnLF
Mean	4.212078	−0.504988	5.985650	16.27248	18.14905
Median	4.273871	−0.424809	6.032609	16.29564	18.18851
Maximum	4.753504	−0.009011	6.261040	16.45170	18.59535
Minimum	3.570096	−1.175706	5.653113	16.03363	17.61582
SD.	0.383435	0.372969	0.197046	0.111385	0.299914
Skewness	−0.315324	−0.386092	−0.319321	−0.576042	−0.244040
Kurtosis	1.767174	1.796575	1.639328	2.413727	1.791692
Jarque-Bera	3.515558	3.748250	4.142037	3.063528	3.113424
Probability	0.172427	0.153489	0.126057	0.216154	0.210828
Correlation analysis					
lnCP	1				
$lnCO_2$	0.986773*** (0.000)	1			
lnEN	0.987035*** (0.000)	0.992296*** (0.000)	1		
lnCR	0.971626 (0.000)	0.963529*** (0.000)	0.958012*** (0.000)	1	
lnLF	0.993407*** (0.000)	0.985700*** (0.000)	0.986756*** (0.000)	0.969063*** (0.000)	1

Note: ***Denotes the rejection of the null hypothesis by the absence of correlation at 1 % level
Source: Researcher's compilation

Table I. Descriptive statistics and the correlation matrix

showing that all studied variables were stationary combinations of I(0) and I(1). This confirms the use of the ARDL-bound test method suggested by Pesaran *et al.* (2001) and by Pesaran and Shin (1998).

3.2 Autoregressive distributed lag bounds testing

The present study applies the ARDL bounds assessment to explain the existence of long-run cointegration. The ARDL long-run cointegration outcomes, reported in Table III, show the existence of long-run cointegrating relationships amongst the production of cereal crops, carbon dioxide emissions, energy consumption, cropped area and the labour force in Pakistan. To check the ARDL approach for stability, several diagnostic tests were applied and checked. The R^2, adjusted R^2 and F-statistic were valid, as given in Table III.

The study also used the Johansen and Juselius cointegration assessment (Johansen and Juselius, 1990) to investigate the presence of long-term cointegration. The outcomes of the Johansen cointegration test, presented in Table IV, revealed that they also showed long-term cointegrating linkages between the independent variables (CO_2 emissions, energy consumption, cultivated area and labour force) and the dependent variable (cereal crops production).

3.3 Long-run coefficients and short-run dynamics

Table V explains the estimates of both the long- and short-run coefficients of the ARDL model. According to the long-run coefficients, energy consumption and CO_2 emissions have a positive impact on cereal crops production, meaning that a 1 per cent increase in CO_2 emissions and energy consumption will increase cereal crops production by 0.20 and 0.11 per cent, respectively. The results of this research are consistent with the results of Janjua *et al.* (2014), Lili *et al.* (2011) and Chandio *et al.* (2018a). Furthermore, in the long run, this research found that cropped area and labour force have a statistically significant and positive impact on the production of cereal crops. These findings can be interpreted that a 1 per cent increase in cultivated area or the labour force will increase cereal crops production

Table II.
Unit root tests results

Variables	Tests	ADF test statistic		PP test statistic		KPSS statistic	
		Intercept	Intercept and trend	Intercept	Intercept and trend	Intercept	Intercept and trend
lnCP	Level	−2.247003	−0.472377	−1.342976	−2.441688	0.824589***	0.194344**
	1st difference	−2.619498*	−3.688592**	−12.49418***	−14.61820***	0.233267	0.188480**
$lnCO_2$	Level	−2.303465	0.219760	−0.611764	−2.192460	0.798242***	0.173827**
	1st difference	−2.732289*	−10.29602***	−8.854989***	−10.29140***	0.188081	0.172586**
lnEN	Level	−1.879681	0.339009	−1.770804	0.339009	0.807794***	0.181579**
	1st difference	−5.160352***	−5.697265***	−5.184510***	−5.697265***	0.376240*	0.139551*
lnCA	Level	−1.059588	−2.602977	−0.999199	−2.602977	0.803078***	0.191269**
	1st difference	−7.584285***	−7.628937***	−7.982182***	−9.484679***	0.111054	0.086092
lnLF	Level	−1.357117	−1.685258	−4.446582***	−1.685258	0.837996***	0.216062**
	1st difference	−4.405490***	−4.446582***	−1.357117	−4.405490***	0.623274**	0.126102*

Notes: Automatic lag length selection based on AIC; ***; ** and *represent statistical significance at 1, 5 and 10 % levels, respectively
Source: Researcher's compilation

$lnCP_t = f(lnCP_t \mid lnCO2_t, lnEC_t, lnCA_t, lnLF_t)$ F-statistic 8.188674[a]		
Significance	I(0) bound	I(1) bound
Critical value bounds		
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06
Diagnostic tests		
R^2	0.549615	
Adjusted R^2	0.459538	
F-statistic	6.101613	
Probability (*F*-statistic)	0.000106	

Note: [a]indicates significant at 1 %
Source: Researcher's compilation

Table III. ARDL-bounds test results

Hypothesized No. of CE(s)	Trace Statistic	0.05 Critical value	Probability
None	116.5694***	69.81889	0.0000
At most 1	63.52499***	47.85613	0.0009
At most 2	31.55501**	29.79707	0.0310
At most 3	12.12888	15.49471	0.1509
At most 4	0.315797	3.841466	0.5741
Maximum eigenvalue			
None	53.04442***	33.87687	0.0001
At most 1	31.96998***	27.58434	0.0128
At most 2	19.42613*	21.13162	0.0852
At most 3	11.81308	14.26460	0.1179
At most 4	0.315797	3.841466	0.5741

Note: ***; ** and *represent statistical significance at 1, 5 and 10 % levels, respectively
Source: Researcher's compilation

Table IV. Johansen cointegration tests

by 0.56 and 0.74 per cent, respectively. Sial *et al.* (2011) found that cultivated area and agricultural labour force have a significant positive effect on agricultural production in Pakistan. Chandio *et al.* (2018b) reported that the total area under cultivation has a significant positive effect on rice productivity in Pakistan. The coefficient of CO_2 emissions in the short run is negatively associated with cereal crops production in Pakistan. CO_2 emissions (a proxy for climate change) may have both positive and negative impacts on cereal crops production. However, this one type of influence may outweigh the other types of effects due to changes in temperature, precipitation and extreme climate events. Furthermore, the study found a positive and significant effect of energy consumption on cereal crops production. The energy consumption coefficient was 0.96 ($P < 0.04$) in the short run, which means that a one per cent increment in the consumption of energy would lead to a 0.96 per cent increase in cereal crops production. The coefficient for the cultivated area showed a statistically significant positive influence on the production of cereal crops, which

Variables	Coefficient	SE	*t*-statistic	Probability
Estimated long-run coefficients				
$\ln CO_2$	0.209601	0.214086	0.979050	0.3343
lnEN	0.115288	0.348949	0.330388	0.7431
lnCA	0.561365**	0.256915	2.185020	0.0357
lnLF	0.749812***	0.166788	4.495592	0.0001
C	−19.118092***	5.028836	−3.801693	0.0006
Estimated short-run coefficients				
ΔlnCP(−1)	−0.001081	0.152381	−0.007096	0.9944
$\Delta\ln CO_2$	−0.191140	0.221681	−0.862230	0.3944
$\Delta\ln CO_2(-1)$	0.400969***	0.147336	2.721449	0.0101
ΔlnEN	0.964148**	0.453684	2.125150	0.0407
ΔlnEN(−1)	−0.848734**	0.417452	−2.033128	0.0497
ΔlnCA	0.571972**	0.240649	2.335231	0.0254
ΔlnLF	0.750622***	0.207070	3.624973	0.0009
ECM(− 1)	−1.001081***	0.152381	−6.569613	0.0000
R^2	0.991364			
Adjusted R^2	0.989636			
F-statistic	573.9448			
Probability (*F*-statistic)	0.000000			
Durbin–Watson stat	2.057348			

Note: ***; ** and *represent statistical significance at 1, 5 and 10 % levels, respectively
Source: Researcher's compilation

Table V. Estimated long- and short-run coefficients from error correction model

means that a 1 per cent increase in the cultivated area would lead to a 0.57 per cent increase in cereal crops production. Our results for cultivated area are consistent with Ahmad (2011), Faridi *et al.* (2015) and Chandio *et al.* (2016), while they contradict the results of Iqbal *et al.* (2003). Faridi *et al.* (2015) revealed that the cropped area has a positive effect on agricultural output. Similarly, the labour force also has a positive impact on cereal crops production. This means that a one per cent increase in the labour force would lead to a 0.75 per cent increase in cereal crops production. These outcomes are in agreement with the research by Ahmad (2011), indicating that the labour force has a positive impact on agricultural productivity.

3.4 Diagnostic tests

After investigating the long- and short-run coefficients of the ARDL model, our research then performed various diagnostic tests (Table VI). The outcomes of diagnostic tests such as the Breusch–Godfrey Serial Correlation LM and ARCH tests showed that the ARDL

Diagnostic tests	*F*-statistic	Probability
Serial correlation	2.084206	0.1405
Normality	3.603798	0.1649
Functional form	0.252985	0.8018
Heteroscedasticity	0.725256	0.3995

Source: Researcher's compilation

Table VI. Diagnostic tests of the ARDL model approach has no problems with autocorrelation. Likewise, the Ramsey RESET and Jarque–Bera tests indicated that the form of the ARDL functional model is correct with no misspecifications and that the residuals were normally distributed. To test the constancy of the ARDL model, the CUSUM and CUSUMSQ tests were used. The plots of CUSUM and CUSUMSQ were within a 5 per cent level of significance (Figures 1 and 2); therefore, the ARDL approach is constant over the period.

3.5 Results of the Granger causality test

This study used the pairwise Granger causality test to check the direction of causality between the variables, and the following linkages were analysed: the causal linkage between $lnCO_2$ (natural logarithm of carbon dioxide emissions) and lnCP (natural logarithm of cereal crops production); the causal linkage between lnEC (natural logarithm of energy consumption) and lnCP (natural logarithm of cereal crops production); the causal linkage

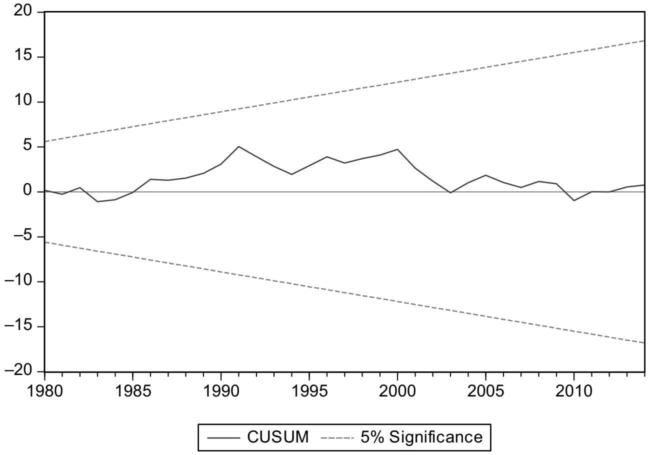

Figure 1.
Plot of the cumulative sum of recursive residuals

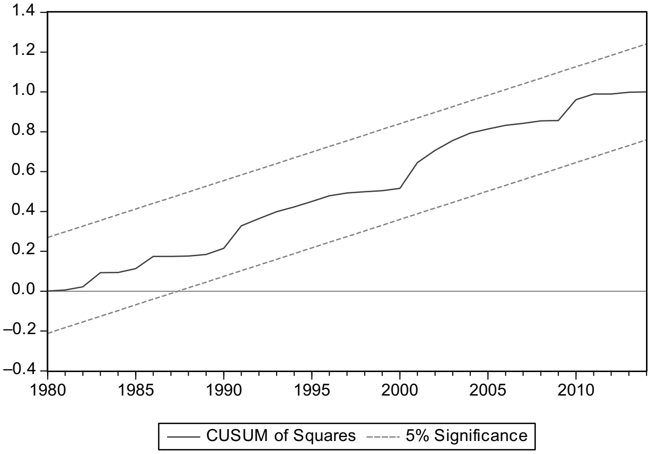

Figure 2.
Plot of the cumulative sum of squares of recursive residuals

between lnCA (natural logarithm of cropped area) and lnCP (natural logarithm of cereal crops production); and the causal linkage between lnLAB (natural logarithm of the labour force) and lnCP (natural logarithm of cereal crops production). The outcomes of the pairwise Granger causality technique are reported in Table VII. The null hypothesis that carbon dioxide emissions do not cause cereal crops production declines is rejected at the 1 per cent significance level. There is evidence of bidirectional causality running from $\ln CO_2 \leftrightarrow \ln CP$. Likewise, the null hypothesis that energy consumption does not increase cereal crops production is rejected at the 5 per cent significance level. There is evidence of unidirectional causality running from lnEC → lnCP. In addition, the null hypothesis that cropped area does not cause cereal crops production increases is rejected at the 10 per cent significance level. There is evidence of bidirectional causality running from lnCA ↔ lnCP. Moreover, the null hypothesis that the labour force does not cause cereal crops production is accepted. There is no evidence of causality between lnLAB and lnCP.

4. Conclusions

Pakistan is an agriculturally based economy which provides 19.8 per cent of the gross domestic product (GDP) and 42.3 per cent of rural areas directly depend on this sector. The main purpose of this sector is to ensure the availability of food for its inhabitants by increasing production levels to cope with the increasing population. Pakistan is highly vulnerable to climate change because of its population growth rate, its geographical location and its traditional technological methods of production. History shows that Pakistan has suffered due to floods and the negative impacts of climate on crops. Research has shown that up to approximately US$14bn is required to cope with the prevailing climate effects on crops yield. Pakistan has a serious weather challenge, which reduces agricultural production because of the probable change in weather and natural droughts, floods and heat waves. In addition, the melting rates of glaciers in Pakistan are higher than for other countries (GOP, 2016). In this research, an effort was made to evaluate the long-run effects of energy consumption, CO_2 emissions, the labour force and cropped area on cereal crops production in Pakistan by interpreting the annual statistics from 1971 to 2014. The study used the Johansen cointegration test and the ARDL method to evaluate the long-run cointegration links between cereal crops production, CO_2 emissions, energy consumption, cropped area and the labour force. Before testing the ARDL-bounds cointegration method, the present research used the ADF, PP and KPSS unit root tests. The estimated outcomes of ARDL-bounds cointegration approach outcomes confirmed the long-term existence of

Null Hypothesis	*F*-statistic	Probability
$\ln CO_2$ does not Granger cause lnCP	11.9239***	0.0013
lnCP does not Granger cause $\ln CO_2$	15.5902***	0.0003
lnEN does not Granger cause lnCP	5.60213**	0.0229
lnCP does not Granger cause lnEN	2.61871	0.1135
LnCA does not Granger cause lnCP	3.25470*	0.0788
lnCP does not Granger cause lnCA	3.08841*	0.0865
lnLAB does not Granger cause lnCP	23.1363	2.E-05
lnCP does not Granger cause lnLAB	0.20656	0.6519

Notes: ***; ** and *represent rejection of null hypothesis at 1, 5 and 10 % levels of significance, respectively
Source: Researcher's compilation

Table VII.
Pairwise Granger causality test results

statistically substantial cointegrating associations among the variables. Outcomes of the long-run coefficients for CO_2 emissions, energy consumption, cultivated area and the labour force have positive impacts on cereal crops production. These outcomes reveal that a 1 per cent increase in CO_2 emissions, energy consumption, cultivated area and labour force will increase cereal crops production by 0.20, 0.11, 0.56 and 0.74 per cent, respectively, in the long run. The Granger causality test shows bidirectional causality running from CO_2 emissions and cultivated area to cereal crops production. Moreover, there is a unidirectional causality running from energy consumption to cereal crops production. On the basis of the study outcomes, it is suggested that, to cope with the adverse effects of climate change, heat- and drought-resistant varieties of improved cereal crops should be developed and introduced to ensure food security for the country. Additionally, the government should control the load shedding of electricity, pay further attention to improving the infrastructure of the energy sector and to increase the supply of electricity in the agricultural sector to boost this sector.

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Corresponding author

Wang Fang can be contacted at: wangfangscnd@sicau.edu.cn

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Local institutions and indigenous knowledge in adoption and scaling of climate-smart agricultural innovations among sub-Saharan smallholder farmers

Clifton Makate
Africa Centre of Excellence in Climate Smart Agriculture and Biodiversity Conservation, Haramaya University, Dire Dawa, Ethiopia

Abstract

Purpose – The purpose of this study is to discuss how enhancing the role of local institutions (LI) and incorporating indigenous knowledge (IK) in climate change adaptation planning can improve adoption and scaling success of climate-smart agriculture innovations.

Design/methodology/approach – A review of relevant literature from sub-Saharan Africa was used to answer the study research questions.

Findings – Embracing IK and LI in climate change adaptation projects can enhance adoption and scaling success of climate-smart agriculture innovations in smallholder farming. Such efforts will improve: information gathering and dissemination, mobilization of resources, establishment of useful networks with relevant stakeholders, capacity building farmers on various fronts and provision of leadership in climate adaptation programs.

Practical implications – Fully embracing IK and LI can improve the scaling of climate-smart innovations only if development partners recognize IK systems that are to be transformed and build on them instead of trying to replace them. Also, participatory approaches in scaling innovations will enhance input from rural people in climate change adaptation programs.

Originality/value – Development interventions aimed at taking proven effective climate-smart innovations to scale must, therefore, engage local communities and their indigenous institutions as active stakeholders in designing, planning and implementation of their climate adaptation programs.

Keywords Traditional knowledge, Local institutions, Climate-smart innovations, Smallholder agriculture, Upscaling

Paper type General review

1. Introduction

Climate change significantly threatens rural livelihoods in sub-Saharan Africa (SSA). This is partly because rural communities in Africa, particularly SSA, are relatively more vulnerable to the effects of climate change (Brooks *et al.*, 2005; Leichenko and O'brien, 2002) than other regions (IPCC, 2014). The vulnerability of the rural communities in SSA to climate change

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effects is a function of several social, economic, physical and environmental processes that increase their susceptibility to climate change effects. For instance, high dependence on rain-fed agriculture (Runge *et al.*, 2004), weak institutional capacities, limited knowledge, inadequate financial and technical resources necessary for climate change adaptation (Rockstrom, 2000), poor production techniques and incompetent policies towards use of productive inputs such as fertilizers and agrochemicals (Clay *et al.*, 2003) and poor governance (Brown *et al.*, 2007) are some of the factors making rural communities in SSA more vulnerable. The SSA region is exposed to climate risk through increased temperature, changes in rainfall patterns and variations in intensity and frequency of extreme weather events such as drought and floods (IPCC, 2014). The estimated impact of climate risk exposure in the region is huge. For instance, climate variability and change are predicted to continue decreasing agricultural production of major cereal crops in the region, including maize, sorghum and millet. Maize, sorghum and millet yields are estimated to fall by 22, 17 and 17 per cent, respectively, by 2050 (IPCC, 2007; IPCC, 2014; Schlenker and Lobell, 2010).

Problems related to weak institutional capacities, incompetent policies and limited knowledge of rural communities in climate change, and how they affect management, are of interest to this research. Evidence exists that the aforementioned can be improved in smallholder farming if climate change adaptation programs integrate local institutions (LI) and indigenous knowledge(IK) systems in climate change management programs (Agrawal, 2010; Ajibade and Eche, 2017).

IK is the institutionalized local knowledge built upon and passed on from one generation to another, usually by word of mouth. IK is often treated as secondary in climate change adaptation debates (Kronik *et al.*, 2010; Nyong *et al.*, 2007), even though it can form the basis for effective adaptation to climate change effects in smallholder farming communities. IK can be important in building climate resilience in smallholder farming communities through a better understanding of ways of promoting climate resilient innovations acceptable in those communities (Mafongoya and Ajayi, 2017), among various other reasons.

Furthermore, the problem of weak institutional capacities can be minimized by giving local community institutions and existing IK systems a central role in climate change management work in SSA. LI here are those localized humanly created formal and informal mechanisms that shape social and individual expectations, behaviour and interactions (Agrawal, 2010; Ostrom, 1990). Given the importance of local adaptation efforts to climate change effects in agriculture, it becomes critically important to better understand the roles that can be played by LI and hence find ways to enhance their contributions towards climate change adaptation. According to Agrawal (2010) LI are critical in effecting climate resilience in rural communities mainly because they:

- mediate between the individual and collective responses to climate change impacts and shape outcomes of climate adaptation;
- they structure the impacts and vulnerability to climate change; and
- they act as a mode of delivery of external support for climate change adaptation, and hence, they govern access to key resources for adaptation (Agrawal, 2010).

Therefore, strengthening the role of IK and LI in climate change effects management is likely to improve adaptation to climate change in smallholder farming communities in SSA. Improved adoption and scaling of climate-smart agriculture innovations are likely to benefit significantly. Research on climate-smart agriculture has shown numerous agricultural technologies and practices that can affect climate change adaptation in agriculture in rural agro-based communities (FAO, 2018). However, adoption of the same proven climate-smart agricultural innovations is still low in developing countries and particularly in the SSA region (FAO, 2018; Nkonya *et al.*, 2018; Teklewold *et al.*, 2013). This article aims to highlight how adoption and scaling of proven climate-smart agricultural innovations in SSA can benefit from enhancing the role played by LI and strengthening efforts toward complementing formal knowledge systems with IK systems in climate change adaptation work in smallholder farming.

Innovations are defined in this article as the workable ideas, practices, products, or changes to rules or processes which involve the extraction of economic, ecological and social values from knowledge (Asenso-Okyere *et al.*, 2008; Meinzen-Dick *et al.*, 2013). Scaling is defined as a series of processes to introduce climate-smart innovations with demonstrated effectiveness, with the aim of improving geographic spread, ensure equitable access to the innovations and enhancing their livelihood impacts, following the definition by Mangham and Hanson (2010). Climate-smart innovations considered in this study include any workable ideas and practices relevant in climate change and variability adaptation in smallholder agriculture from weather-related, water related, seed/breed related, carbon/nutrient related and market/institutional related practices (see Table I).

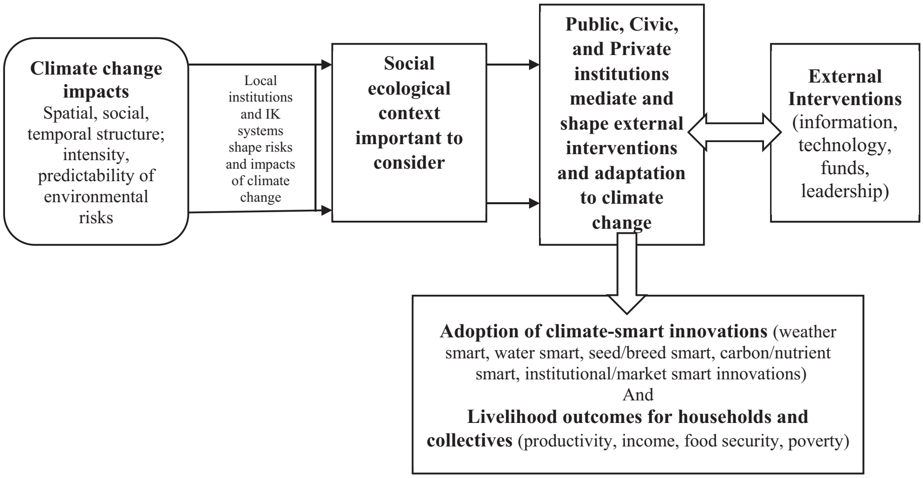
The rest of the article is organized as follows. Section 2 outlines the study conceptual framework, while Section 3 presents a summary of the approach used in selecting relevant literature. Section 4 discusses how LI can be critical in spreading climate-smart agriculture innovations in smallholder agriculture while Section 5 gives a discussion on how incorporating IK systems can be of help in improving adoption and scaling of climate-smart agriculture innovations. Section 6 discusses necessary actions that need to be taken to enhance the role played by LI and IK systems, in adoption and scaling of climate-smart agriculture innovations in smallholder farming. Section 7 concludes the article.

2. Conceptual framework

The study relied on the adaptations, institutions and livelihoods (AIL) framework to critically analyze the potential influence of LI and IK systems in improving the adoption of climate-smart innovations in smallholder agriculture. Figure 1 summarizes the AIL framework. The AIL framework here shows how LI and IK shape the problem's (climate change) impact in society and also how adaptation and mitigation of the problem can be affected by the same institutions and IK systems. This study applies the same conceptual framework to see how LI and IK can affect the adoption and scaling of climate smart innovations of demonstrative effectiveness in smallholder agriculture. Several innovations are considered climate-smart in this study. Some of the innovations considered climate-smart are summarized in Table I.

Table I. Example of climate smart innovations that LI can help in upscaling for improved climate resilience in smallholder agriculture

Innovation category	Weather smart	Water smart	Carbon/ nutrient smart	Seed/breed smart	Institutional/market smart
examples	Weather forecast services Agro advisory services Weather insurance (e.g. index-based insurance)	Solar pumps Rain water harvesting Watershed management Small-scale irrigation	Conservation agriculture Integrated soil fertility management Agroforestry Crop diversification	Adapted crop and livestock species (e.g. drought tolerant maize and, indigenous livestock breeds) Community seed banks	Market information Credit Government subsidies Cross-sector linkages Membership to community institutions



Source: Adapted from Agrawal (2010)

Figure 1.
Conceptual framework

The climate-smart innovations given are considered essential in effecting the upgrading of smallholder value chains in the face of climate change and variability.

According to the AIL framework, LI and IK structure the impacts of climate risks on smallholder farming households in a given social-ecological context. That is, LI or IK systems can determine the extent of harm by climate change to locals (e.g. local farmers).

In cases where strong LI or IK systems exist, farmers or local people can be supported to be resilient to the climate change shock, which may not be the case where weak institutions exist. Also, LI shapes the nature and degree to which households respond either as individuals or collectively. Where LI or IK systems are functional, necessary support can be given to farmers, which can aid their adaptation to climate shocks. It, therefore, implies that institutions and IK systems can influence (promote or discourage) collective action in the adoption of climate-smart innovations.

As highlighted in the AIL framework, LI and IK systems can also mediate the influence of the outside world in terms of adaptation to climate change. This implies that LI and IK systems in smallholder farming systems can determine external support in terms of finance, knowledge and other climate-smart interventions a particular community can receive. For instance, hostile LI who cannot form meaningful pacts with the external world limit support coming to their communities. Conversely, LI that develops a good rapport with external stakeholders may be better off in bringing resources (knowledge, finance, technologies) to the parent communities. This makes LI very important in climate change management in smallholder farming.

However, the effects of LI and IK systems will not be uniform across communities of varying socio-ecological contexts. Various factors will determine the exact manner and the extent to which LI and IK systems influence the adoption of climate smart innovations. As given in Agrawal (2010), nature and severity of climate change-related stress, household and community attributes and social and political contexts within particular local communities, among others, are some of the critical factors that can influence the exact manner in which LI can influence uptake of climate smart innovations. Also, community people's perceptions and trust in the available LI and IK systems are critical factors. Community people (including farmers) are more likely to embrace LI and IK systems if they believe and trust in them Nyong *et al.* (2007). In addition, it is important to note that climate change adaptation is context-specific. Hence, the influence of LI or IK cannot be assumed to be the same on the adoption of different climate smart innovations.

In summary, the AIL conceptual framework shows how LI and IK systems influence: extent of climate change impacts felt by community people, how LI and IK systems can give first line defence in effecting adaptation to climate shocks (using local community resources) and how LI and IK systems can influence external support coming to the community to effect adaptation.

3. Review approach

The article is a synthesis of relevant published evidence on the role of IK and LI in upscaling adoption and impacts of climate-smart agricultural innovations in smallholder agriculture. Contender publications were identified mainly through Google Scholar search and forward searches of publications that cited relevant studies for the research topic. The Google literature search used several key words and phrases to gather relevant studies. Published literature was included in the analysis as long as it addressed any of the following:

- what IK or LI are and their roles/importance in adoption and scaling of technologies in agriculture; and
- how to enhance contribution from IK and LI in adoption and scaling of climate-smart innovations in smallholder agriculture.

Important to note, however, is that other supporting literature was cited outside the criteria given. For instance, some literature cited in building the introduction was not strictly selected based on the inclusion criteria. A flow chart summarizing the approach adopted in selecting literature is shown in Figure 2.

From about 105 candidate publications that were reviewed (mainly by reading the title and or abstract), only 81 met the inclusion criteria. All literature referred to in this review were accessed and read.

4. What role local institutions can play in the adoption and scaling success of climate-smart innovations?

4.1 What are local institutions?

As highlighted earlier, LI are those localized humanly created formal and informal mechanisms that shape social and individual expectations, behaviour and interactions. Informal institutions are the set of informal rules that exist outside and alongside the structure of government while formal institutions are the laws and public policies written and documented (Raymond and Weldon, 2013). Both formal and informal institutions influence human behaviour and are, therefore, important in climate change management, especially in smallholder farming communities. LI important in climate change management can be categorized into civic, public and private institutions. Public institutions include the local governments (village and district administration), government agencies (e.g. research and extension agencies operating at local levels), while civic society institutions include local farmer organizations, cooperatives, savings and loan groups, local churches and other civic society groups based in local communities. Private institutions may include non-governmental organizations (NGOs), Charity organizations and private businesses (e.g. local agro-dealers in seed, fertilizer, agrochemicals, insurance, loan dealers).

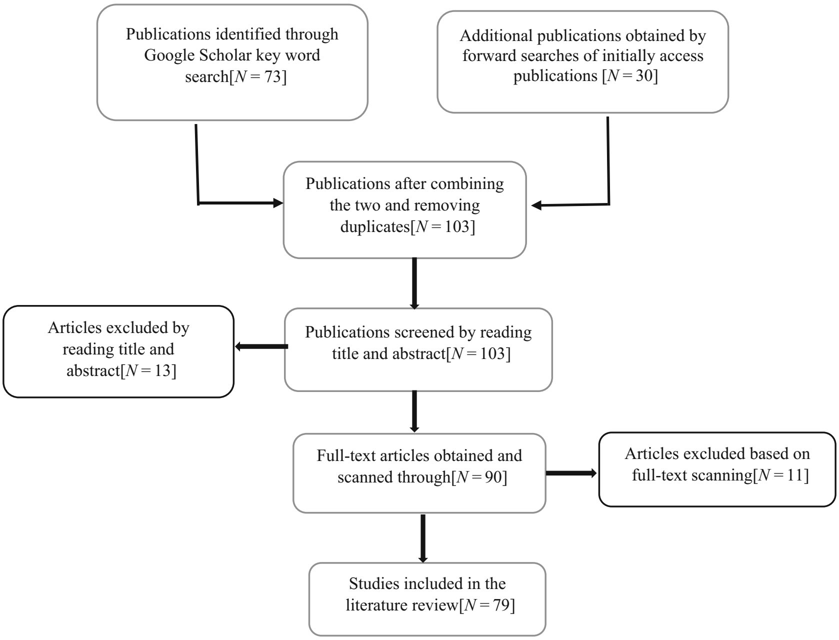


Figure 2.
Flow diagram summarizing the approach used in the selection of literature

Examples of informal institutions can include women savings groups, traditional leadership, labour sharing groups and indigenous information exchange groups.

4.2 In what ways can local institutions be important in the adoption and scaling of climate-smart innovations?

As explained earlier under the study conceptual framework, LI are important in three aspects when it comes to climate change management debates:

1. They shape climate change impacts in a particular society.
2. They determine the type of adaptations actions taken by the people.
3. They determine external support coming to the local communities in climate change effects management.

Relevant to this article is the possible influence of LI on adaptation actions taken by farmers and the level of external support received by local communities.

It is evident from reviewed literature that LI in rural communities can be key in improving adoption and scaling success of innovations mainly through their influence on information gathering and dissemination on available innovations, skills development and capacity building, resource mobilization, creating networks, providing leadership among other functions (Agrawal, 2010; Raymond and Weldon, 2013) which are key elements for awareness and subsequent adoption of proven climate-smart innovations. Literature agrees to the fact that LI is key in facilitating the adoption and scaling of agricultural technologies (Ajayi *et al.*, 2018; Meinzen-Dick *et al.*, 2013). However, the effective participation of LI in the adoption and spread of climate-smart innovations is basically driven by their interests. For instance, private sector institutions will be more interested in making profit out of their involvement in adoption and dissemination of climate-smart innovations, while the public institutions may be more interested in promoting adoption and scaling of innovations with benefits of more public than private good nature (Meinzen-Dick *et al.*, 2013). Practical examples include that of seed companies promoting adoption of stress adapted crop varieties and local government agencies pushing for resuscitation or development of irrigation infrastructure. Seed companies may have the prime aim of making a profit and growing their business, but it may not be the case for the local government due to the public nature of the irrigation infrastructure. In addition, local-level institutions, particularly informal institutions may be interested in promoting adoption and scaling of local-level climate-smart innovation options, e.g. locally adapted crop and livestock species or their innovations. For instance, in Tanzania evidence show that farmers innovate by developing their climate-smart agricultural practices (e.g. in erosion control, livelihoods diversification and changing cropping dates and patterns), which they aim to upscale (ActionAid, 2014). Also, in Ghana, farmers were reported to be more interested in promoting their climate-smart innovations (e.g. suppression of striga using onion residues) (Tambo and Wünscher, 2014).

Important to note, however, is the fact that, in some instances, local institutional arrangements can act as barriers to scaling of innovations. For example, unfavourable institutional arrangements in property rights, cultural views towards innovation, and gender norms may limit spread of innovations in rural communities. As alluded in Meinzen-Dick *et al.* (2013) at times, existing LI beliefs, cultural norms and practices may impede the adoption of certain innovations and hence make it more difficult for farmers to experiment and try new activities. Despite the possible drawbacks of LI, the following points highlight how LI can be important in promoting innovation, adoption and spread of climate-smart innovations through strengthening:

- access to climate-smart information services;
- skills development and capacity building;
- resource mobilization;
- building effective social networks; and
- ensuring visionary leadership.

4.2.1 Local institutions and climate-smart information provision. Access to information on climate-smart innovations like any other agricultural innovations is a necessary step for their adoption. This, therefore, means the ability of LI to convey information on relevant climate-smart agricultural innovations can be very important for adoption and scaling of such innovations. Climate-smart information services are essential as they inform farmers on current trends in climate and on various adaptation measures farmers can take. As derived from literature, state institutions are usually the providers of various information services, including weather and technical information services, mainly through agro-advisory services (Meinzen-Dick *et al.*, 2013). However, a lot of information gaps exist and act as barriers (costs) to the adoption of climate-smart innovations. According to McCarthy *et al.* (2011), the costs of searching for such critical information pose a significant barrier to the adoption and scaling of climate-smart innovations. Precisely, climate information services in agriculture have been reported to be narrowly focused (Levine *et al.*, 2011; Newsham and Thomas, 2011) and they diverge with local farmers' needs (in terms of accuracy, format, scale, preference and content of available products) (Vermeulen *et al.*, 2012). Moreover, formal climate information services have been reported to ignore local farmer perceptions, and differential farmer information needs (Chaudhury *et al.*, 2012;

Meinzen-Dick *et al.*, 2013), and this has made them less effective in availing efficient climate-related information services that can improve adaptation, through adoption and scaling of climate-smart innovations. Enhancing the role of LI, particularly informal institutions in providing climate information services can bridge the gaps, reduce costs of searching for information, and hence provide information which suits local farmer needs. In addition, enhancing the role played by LI can ensure equality in the provision of information by the socioeconomic status of farmers (i.e. wealth or gender). This is plausible because literature has noted that women or poor farmers who are excluded by formal information provision channels often resort to informal networks and exchanges (Meinzen-Dick *et al.*, 2013). For instance, kinship and informal social networks were found to be essential in information dissemination about improved seed and improved fallow in Kenya (Kiptot *et al.*, 2006). To boot, in western Kenya, local institutional partnerships, including churches, women groups, NGOs, youth groups, local leadership, government agencies amongst other local-level institutions were found to strengthen information flow and awareness on agroforestry practices (Qureish *et al.*, 2001).

4.2.2 Local institutions in skills development and capacity building for climate resilience. It is evident from the literature that LI can also be important in providing skills development and capacity building for farmers with regards to climate-smart innovations and related services (FAO, 2018). For instance, it is alluded in Zilberman *et al.* (2012) that diffusion of technology adoption as an adaptation to climate change is a function of prevailing institutions that can foster or hinder adoption. Prevailing LI can encourage adoption by offering training, improving education and awareness on new or improved climate-smart innovations at the local level. Training needs for farmers have been traditionally provided by formal agricultural extension services in developing countries, including SSA (Aker, 2011; Anderson and Feder, 2007). However, most of the agriculture extension systems have been regarded not fit for purpose particularly when it comes to providing climate adaptation needs for farmers (HLPE, 2012) mainly because climate change itself is a new complex challenge which requires specialized training needs.

In Western Zimbabwe (Nyami Nyami area located in Kariba Rural district council), various local-level institutions (such as Christian Care, Red Cross, government extension and Save the Children) have been reported to offer training and skills development in climate change adaptation work (Mubaya and Mafongoya, 2017). Civic organizations and NGOs, in partnership with local traditional leadership, were noted to have contributed to the training of farmers in climate change management. LI were also reported to be actively improving the adaptive capacities of the rural people by offering various services including the drilling of wells, provision of water and sanitation services and offering disaster response preparedness services (Mubaya and Mafongoya, 2017). Such actions improve the adaptive capacities of local community people, including farmers. Also, churches have been reported to be active participants in capacitating farmers to adapt to the changing climate. For instance, in Kenya, church leaders are reported to be at the forefront in educating communities on climate change adaptation (Nzwili, 2014) in addition to advocating for external help from the developed world in climate change management. Also, research institutions such as ICRAF in Zimbabwe, Mozambique, Malawi and Zambia were noted as key participants in training farmers and local change agents in agroforestry technology establishment and management (Setimela and Kosina, 2006). Further, evidence exists in SSA of local community-level institutions improving capacities and skills of farmers for climate change adaptation. For instance, innovation platforms (IP) and cooperatives are reported to be improving capacities for farmers in problem identification and proffering of sustainable solutions to identified problems in farming communities (Abebaw and Haile, 2013; Ajayi *et al.*, 2018; Verhofstadt and Maertens, 2014).

4.2.3 Local institutions and resource mobilization for climate-smart innovation adoption. Further, it is evident from the literature reviewed that enhancing the role of LI in climate-smart agriculture work can also assist in resource mobilization, which is critical for the adoption of climate-smart innovations by farmers. It is evident in the available literature that access to resources significantly explains the adoption of agricultural technologies (Lansing and Markiewicz, 2011; Legese *et al.*, 2009), which is also true for climate-smart innovations. It, therefore, implies that for effective adoption and scaling of innovations in poor communities there is need for sustainable resources support. As much as LI (through social capital and networks) critically help in sourcing resources locally, as climate change effects worsen, it may be necessary to consider adoption of a diverse set of climate-smart innovations, or new set of innovations which require more resources. In this case, external support will be required to improve farmers' capacity to adopt new innovations. This explains why Church leaders in Kenya have joined other stakeholders in advocating for support from developed countries (who have immensely contributed to carbon emissions) in local climate change management (Nzwili, 2014). LI can also help external institutions to align their interventions with local needs, which enhance the effectiveness of such external interventions. According to Agrawal (2010), all external interventions in climate change adaptation for rural communities need local institutional collaborations for the effectiveness. However, the level of collaboration with LI will depend on the type of innovations to be adopted by farmers (Meinzen-Dick *et al.*, 2013). For instance, adoption actions at individual farmer level, e.g. adoption of stress-adapted crop and livestock species may not require much in terms of institution coordination when compared to higher level (community level innovations) e.g. building of a community water reservoir. At such levels, collective action institutions involving both formal and informal institution collaborations are most appropriate.

Some notable examples exist across SSA, where LI have influenced resource mobilization in farming communities. LI, such as farmer cooperatives, community groups, community financing schemes, women savings groups, among others, have been reported important in mobilizing resources for climate change management. For instance, in Malawi, credit savings groups have been reported to be key in mobilizing inputs and resources for small and medium enterprises, including farmers (Chipeta and Mkandawire, 1992; GOM, 2006). Further, farmer cooperatives in Rwanda and Ethiopia were reported to be key in enhancing farmers' access to farming inputs and other resources (Abebaw and Haile, 2013; Makate, 2019; Verhofstadt and Maertens, 2014). However, as reported in Preker *et al.* (2001), the main weakness of some LI such as community financing schemes are the low volume of resources that can be mobilized in poor communities, the frequent exclusion of the very poorest members from participation in such groups, limited management capacity and relative isolation from more comprehensive benefits from resource providers (e.g. formal banks).

To sum up, the local level institutions play a key role in structuring access to and control over resources, in addition to facilitating access to resources outside of communities.

4.2.4 Local institutions in network building. LI also assists in building useful networks (linkages), which can be crucial in enhancing the adoption of climate-smart innovations. Social capital is shown to explain adoption of climate-smart interventions in literature (Isham, 2002; Teklewold *et al.*, 2013), and for this reason, development interventions in rural communities have been found to rely on networks and group-based approaches in tackling different kinds of problems (Meinzen-Dick *et al.*, 2013). For the same reasons, agricultural research and development institutions in SSA are promoting participatory approaches (e.g. integrated agricultural research for development through IPs) (Mango *et al.*, 2015) to improve useful linkages/networks of farmers with key-value chain actors. Effective networks will ensure that farmers are linked to key agricultural value chain actors, e.g. input and output markets and that the farmers receive necessary information about innovations. Informal institutions (IK, norms and kinship ties) are an alternative in cases where formal institutions have failed to serve community needs in building useful linkages for agricultural technology transfer (Matuschke, 2008; Newsham and Thomas, 2011). In addition, the promotion of farmer to farmer extension models in scaling agricultural technologies in SSA by research and development partners provide more evidence on the importance of LI in building networks for improving climate change management (Ajayi *et al.*, 2018). Such extension models bank on farmer social networks to enhance adoption and spread of technologies in smallholder agriculture. The overall implication is that, at the local community level, institutional linkages, social networks and social capital can be vital in facilitating and supporting adoption and scaling of proven climate-smart innovations.

4.2.5 Local institutions in governance and political advocacy for climate-smart agriculture. LI can also be important in ensuring adequate leadership for climate change management projects in rural communities (Makate, 2019). The importance of LI can be in the form of creating a conducive environment for climate change management work or direct support towards climate change management interventions. Furthermore, LI, such as churches, traditional leadership, schools and other societal groups, can enhance climate change management work through lobbying for political will and support from political players (Ajayi *et al.*, 2018). Political support is essential in expanding and sustaining climate-adapted innovations adoption and scaling projects (FAO, 2009; Kohl and Cooley, 2003). Important to note, however, is that the focus should be on building coalitions of political stakeholder support and commitment as political parties come and go while adoption and scaling up works are long-term processes. If not managed carefully, political advocacy can bring risks to the adoption and scaling process. In literature, some scaling projects failed to get political support by current leaders because scaling initiatives were initiated by political rivals (Roothaert and Kaaria, 2004). LI should, therefore, provide adequate leadership and support in lobbying for sincere support by political players in climate change management works, for effectiveness. In leadership, attributes such as accountability, vision, among others, are essential as well. In cases where local leadership lacks vision and accountability, LI can be pure sources of inertia and corruption (Lowndes, 1996), which can act against successful adoption and spread of climate-smart innovations.

5. Indigenous knowledge (IK) and climate-smart agricultural innovations

5.1 Indigenous knowledge and its characteristics

5.1.1 What is indigenous knowledge? IK is the institutionalized local knowledge built upon and passed on from one generation to another, usually by word of mouth (Osunade, 1994). Various organizations have come up with various working definitions for IK. For instance, Convention on Biological Diversity (2001) defines traditional knowledge as the knowledge, practices and innovations of indigenous and local communities around the world. The United Nations Educational Scientific and Cultural Organization (UNESCO) (2002) defines IK as the understandings, skills and philosophies developed by societies with long histories of interaction with their natural settings. Similarly, the World Intellectual Property Organization (2004) defined IK as the skills, know-how, innovations, practices passed on from generation to generation in a traditional context and that form part of traditional lifestyle of the indigenous people and communities.

5.1.2 Characteristics of indigenous knowledge. All the definitions of IK support the idea that IK is developed from experience gained over time and is adapted to local community cultures and their environment. Also, traditional knowledge is transmitted orally from one generation to another, and it tends to be collectively owned. IK is often in the form of stories, proverbs, folklore, cultural values, rituals, beliefs, community laws, local languages and agricultural practices (Convention on Biological Diversity, 2001). IK is also key to decision making on aspects of day to day life for the rural people.

5.2 Role of indigenous knowledge in the adoption and scaling of climate-smart agriculture innovations

How can IK be useful in the adoption of climate-smart agriculture innovations in smallholder farming in SSA? It is unanimously agreed in literature that utilization of IK by rural communities in poverty-stricken areas in SSA has helped them to thrive in extremely harsh environments in the past (Hart and Mouton, 2005; Van Veldhuizen *et al.*, 1997). Historically, IK is said to have contributed significantly to developments in agriculture worldwide, such as domestication of crops and livestock, conservation of agrobiodiversity resources, development of animal traction and exchange of plant and animal species (Mettrick, 1993). This implies that IK can be critically important for scaling climate-smart innovations in smallholder agriculture. Policymakers and other stakeholders interested in improving adoption of CSA innovations need to understand that, rural communities have been adapting to climate change even before in various innovative ways and that external interventions can only be successful if they build on what already rural farmers have been doing to adapt to climate. According to Altieri (2004), traditional farmers have developed diverse and locally adapted agricultural systems for centuries, and have managed them with indigenous practices that were often effective in ensuring food security and sustainability (Altieri, 2004).

Literature has shown that indigenous people have been excellent in providing weather-smart information services (Mafongoya and Ajayi, 2017) for agriculture. Literature from SSA confirms the reliance on tree phenology, animal behavior, astronomy and moon movements, just to give a few examples, by indigenous people to predict climate (i.e. onset of rains, and season quality) (Kalanda-Joshua *et al.*, 2011; Mafongoya *et al.*, 2017; Roudier *et al.*, 2014). For example, in Zimbabwe, indigenous people profoundly relied on studying life cycle of trees and animals to predict events of the climate system, including rainfall, wind, floods, temperature and seasonal changes to drought (Chanza and de Wit, 2015). In Muzarabani, Zimbabwe, indigenous people were found to use *munanga* (*Acacia nigrescens)* blossoms to predict early onset of the rainy season, abundance of termite colonies seen collecting biomass into their mounds, the appearance of migratory birds and large number of Christmas beetle (*Anoplognathus* spp.), to be associated with normal or above normal rainfall season, with a possibility of flooding in low lying areas (Chanza, 2014; Chanza and Mafongoya, 2018). Indigenous climate services in the aforementioned literature are highly praised for offering climate services that are at a much-required high resolution (local scale). It therefore means, embracing indigenous weather-smart innovations can complement scientific formal weather services as they are often given at lower resolutions (high temporal and spatial depth) (Mafongoya *et al.*, 2017).

Also, indigenous people have been promoting seed/breed climate-smart agricultural innovations in an attempt to adapt to climate change. For instance, in SSA, rural farmers have always diversified their farming/livelihood systems by including underutilized crop, livestock and insect species (Jiri *et al.*, 2017), and have been promoting local crop and livestock breeds (Liwenga, 2017; Mafongoya and Ajayi, 2017). It, therefore, means scaling climate-smart innovations can learn and build from what local communities have been doing in adapting to climate in such communities in the past. Likewise, in soil fertility management, farmers have been using traditional methods to improve soil quality, e.g. land fallow (Sanchez, 2002; Vanlauwe *et al.*, 2010). In Lesotho, indigenous farmers have used traditional farming systems, e.g. the *Machobane farming system* (Mafongoya and Ajayi, 2017), to improve soil fertility under climate change.

Further, adoption, scaling and sustainability of water-smart innovations, such as rainwater harvesting, have also benefited from IK systems in SSA (Mbilinyi *et al.*, 2005; Reij *et al.*, 2013). The success of such systems has been mostly because of the compatibility of water-harvesting systems with local styles, LI and local social systems.

Adoption and scaling of innovative practices in natural resources management have also benefited from IK (Luoga, 1994; Luoga *et al.*, 2000). Three key features of IK that are important in indigenous resources management include social organization that control access to natural resources in the community, indigenous utilization techniques for conserving and preserving resources, and the customary norms and procedures for control, acquisition, maintenance and transfer of natural resources (Luoga, 1994; Luoga *et al.*, 2000).

What it means then is that, actions of development partners, both private and public, to enhance adoption and scaling of climate-smart innovations, should first understand and learn from indigenous communities on what they are already doing in terms of climate change management, and then build on such efforts in promoting adoption and scaling of innovations. This becomes more important as it has been found in the past that in areas characterized by modern agricultural practices, traditional practices are often disrupted and IK is abandoned (Altieri, 2004).

6. How indigenous knowledge and role of local institutions can be enhanced for improved resilience to climate change in sub-Saharan Africa

With impeccable evidence that IK and LI play a critical role in the adoption and scaling of climate-smart innovations, the key question will then be how to effectively embrace IK and LI for effective adoption and scaling of climate-smart innovations. This article highlights some important considerations that can enhance role of IK and LI in climate change management.

6.1 Enhancing the role of local institutions

The role of LI can be enhanced in various ways. Useful partnerships amongst LI themselves, for example, is one way of getting the best out of LI in performing their role in scaling climate-smart innovations. In SSA, we have seen the rise of the IP approach (Fatunbi *et al.*, 2016), which aims to promote innovative farming practices through useful partnerships of smallholder value chain actors, including farmers, input suppliers, researchers, marketers, and LI. Such partnerships, through the IP, give voices not only to farmers but also LI, which increases the likelihood of meeting local community needs in terms of climate-smart innovations.

In addition, there is a need to improve the capacities of the LI to enhance their effectiveness. That is to say, capacity building LI with the necessary resources (human capital, financial, technology, information, etc.), is also key if they are to be real champions in taking climate-smart innovations to scale. Also, LI must have useful partnerships with the external world for them to be effective in their role. As climate change effects worsen, LI alone may not effectively keep pace with adverse impacts; hence, they will need to have useful and effective partnerships with the external players, to build upon their capacities.

Moreover, to improve the adoption of climate-smart innovations at the community level, there is a need to give LI who are directly linked to farmers a central role in promoting the innovations. LI must be handed central responsibilities in designing, planning and implementing policies, projects and programs meant to scale adoption of the innovations (Meinzen-Dick *et al.*, 2013). Further, LI are also important as they can promote innovation in local communities (ActionAid, 2014; Tambo and Wünscher, 2014). However, for this to happen, and as highlighted earlier, there is need for investment in capacity development/building of LI. It, is however, important that external players understand which LI are present in the communities they will be targeting, including their capacities, interests, connections, challenges and strengths before offering external support. With this, they can increase chances of success for their interventions, by complementing activities of LI already working in such communities.

LI must be visible in designing, planning and implementing of projects which aim to improve the adoption of climate-smart innovations. Further, research on what kind of institutional arrangements best facilitate the adoption of climate-smart innovations across space and time should be a priority for evidence-based decision making.

6.2 Getting the best from indigenous knowledge systems in scaling climate-smart innovations

The literature reviewed has shown IK to be critically important for climate change adaptation in rural communities. For instance, Nyong *et al.* (2007) found the sustainability of agricultural projects in local areas to be highly sustainable if local people are seen as partners in the project with joint ownership. It, therefore, implies that IK can never be ignored in efforts to promote sustainable agriculture under the changing climate.

The noble thing to do to get the best out of IK systems in spreading climate-smart innovations will be recognizing its existence and then incorporating it into designs, plans, and implementation frameworks for promoting innovations. Incorporating IK can be done best by seeing local community people and their LI as core stakeholders in climate change management. Agricultural projects for building resilience to climate change should see local communities as equal partners in development. It is highly important that indigenous people should carry greater responsibilities for their development and external partners should only back their efforts. In support, an electric combination of old and new knowledge, in a mixture made and controlled as far as possible by the rural people themselves may yield positive impacts. This can be accomplished by creating the conditions in which traditional rural knowledge can change from being mainly a system of classification to being also a means for setting in motion cumulative change (Swift, 2009).

In addition, capacity building by external partners should emphasize the need to build on what already exists as IK plays a significant role in the sum total of what exists in a local community (Nyong *et al.*, 2007). Also, a bottom-up approach is desirable if development partners are to get the best out of IK systems. If development partners adopt a bottom-up approach, it will ensure high level participation of local communities which hence improve chances of success. Bottom-up approaches will be important as they provide insight to development partners on how communities and households interact. In addition, the bottom-up approach gives a chance to local communities to acquire necessary skills for them to forge their own paths to sustain agricultural development programs.

Most importantly, IK should not be developed or harnessed as a substitute for formal scientific knowledge. The objective should be to find best ways of complementing IK and formal knowledge systems for enhanced climate resilience in smallholder farming. This is plausible because research has found that a hybrid of external institutions and indigenous practices enhance adaptive capacity and resilience of local communities to climate change (Upton (2012) for an example in pastoral communities).

7. Conclusion

Several concluding points and recommendations are derived from this research:

- First, it is clear from the study that LI are important for climate change management in smallholder farming communities in rural Africa. They have a big role to play in guiding successful adoption and scaling of climate-smart agricultural practices of demonstrated effectiveness. The research and development community should therefore give LI a central role in works aiming to improve adoption and scaling success of climate-smart agricultural innovations in SSA.
- Second, IK is also a backbone of adaptive management in smallholder farming communities in Africa. IK has helped communities adapt to harsh environments in the past and will certainly continue to help them adapt to harsh environments (e.g. climate change) now and in future.
- Third, establishing useful partnerships of LI at community level and also with the external world (outside communities) is likely to enhance their effectiveness. In addition, capacity building of LI and their personnel and improving their access to resources is vital for their effectiveness in promoting adoption of climate-smart innovations.
- Fourth, to get the best out of IK, research and development partners should find ways of complementing IK with scientific knowledge in climate change management works targeting rural communities. The mixture of old and new knowledge, however, should be made and controlled as far as possible by the indigenous people themselves.

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Corresponding author
Clifton Makate can be contacted at: ruumakate@gmail.com

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