The International Journal of Climate Change Strategies and Management addresses the need for disseminating scholarly research, projects and other initiatives, such as new policies, strategies or action plans, which may lead to a better understanding of the subject matter of climate change. The journal publishes papers dealing with policy-making on climate change, on methodological approaches to cope with the problems deriving from climate change and disseminates experiences from projects and case studies where due consideration to environmental, economic, social and political aspects is given and especially the links and leverages that can be attained by this holistic approach.

EDITOR
Professor Walter Leal Filho, BSc, PhD, DSc, DPhil, DL, DLitt, DEd
Head of the Research and Transfer Centre, Hamburg University of Applied Sciences, Faculty of Life Sciences, Lohbruegger Kirchstrasse 65, 21033 Hamburg, Germany
E-mail walter.leal@hs-haw-hamburg.de

DEPUTY EDITORS
Dr Gustavo Nagy
Universidad de la Republica, Uruguay
E-mail gustavo.nagy56@gmail.com

Dr Artie Ng
Hong Kong Polytechnic University, Hong Kong
E-mail partie@speed-polyu.edu.hk

Dr Mihaela Sima
Institute of Geography, Romanian Academy, 12 Dimitrie Racovita St., Sector 2, Bucharest, Romania
E-mail simamik@yahoo.com

ASSOCIATE EDITORS
Professor Abu Quasem Al-Amin
University of Technology of Malaysia, Malaysia

Dr Paula Castro
University of Coimbra, Portugal

Professor Ana Coelho
Federal University of Rio de Janeiro, Brazil

Professor Harry Diaz
University of Regina, Canada

Professor Margot Hurlbert
University of Regina, Canada

Professor Jesse Keenan
Columbia University, USA

Dr Gustavo Nagy
Universidad de la Republica, Uruguay

Dr Johanna Nalau
Griffith University, Australia

Professor Dan Orcherton
National University of Fiji, Fiji

Leisa Perch
World Centre for Sustainable Development, Brazil

Dr K. Ravi Shankar
Centra Research Institute for Dryland Agriculture (CRIDA), India

Professor Belay Simane
Addis Ababa University, Ethiopia

EDITORIAL ASSISTANT
Jelena Barbir
International Climate Change Information Programme, Spain
E-mail jelena@barbir.com.es

ISSN 1756-8692
© 2019 Emerald Publishing Limited

Guidelines for authors can be found at: www.emeraldgrouppublishing.com/ijccsm.htm

International Journal of Climate Change Strategies and Management is indexed and abstracted in:
Current Contents ©Social and Behavioral Sciences
Journal Citation Reports/Social Sciences Edition
QUALIS
Social Sciences Citation Index ©
EDITORIAL ADVISORY BOARD

Dr Keith Bettinger  
USAID Adapt Asia Pacific, Thailand

Professor Branko Bosnjakovic  
Regional Adviser on Environment, Switzerland

Dr Luigia Brandimarti  
University of Uppsala, Sweden

Dr Jackson Efitre  
Makerere University, Uganda

Dr Guy Félio  
R.V. Anderson Associates, Canada

Dr Stefan Hochrainer-Stigler  
International Institute for Applied Systems Analysis, Austria

Professor Arvo Iital  
Tallin University of Technology, Estonia

Professor Maris Klavins  
University of Latvia, Latvia

Dr Debora Ley  
Regional Clean Energy Initiative, TetraTech, USAID, USA

Erik van Lennep  
Circle Squared Foundation, Spain

Dr Gilma Mantilla  
Columbia University, USA

Professor Jose Marengo  
National Institute of Space Research, Brazil

Dr Fialho P.J. Nehama  
Universidade Eduardo Mondlane, Mozambique

Vincent N. Ojeh  
Federal University of Technology, Nigeria

Professor Emmanuel Olukayode Oladipo  
University of Lagos, Nigeria

Dr Isaac Oluwatayo  
University of Limpopo, South Africa

Professor Aydin Ozdemir  
Ankara University, Turkey

Tarcisio Hardman Reis  
United Nations Environment Programme, Switzerland

Dr Rajendra Shrestha  
Asian Institute of Technology, Thailand

Professor Pablo Torres-Lima  
Universidad Autonoma Metropolitana, Mexico

Dr Michael van der Valk  
Hydrology.nl, Netherlands

Dr Liang Yang  
University of Hamburg, Germany

Professor ZhongXiang Zhang  
Tianjin University, People’s Republic of China
The global carbon budget and the Paris agreement

Olga Alcaraz, Pablo Buenestado, Beatriz Escribano, Bàrbara Sureda, Albert Turon and Josep Xercavins

Group on Governance of Climate Change of the Research Group on Sustainability, Technology and Humanism, Barcelona East School of Engineering – EEBE, Polytechnic University of Catalonia, Barcelona, Spain

Abstract

Purpose – The main purpose of this paper is to introduce the concept of global carbon budget (GCB) as a key concept that should be introduced as a reference when countries formulate their mitigation contributions in the context of the Paris Agreement and in all the monitoring, reporting and verification processes that must be implemented according to the decisions of the Paris Summit.

Design/methodology/approach – A method based on carbon budget accounting is used to analyze the intended nationally determined contributions (INDCs) submitted by the 15 countries that currently head the ranking of global emissions. Moreover, these INDCs are analyzed and compared with each other. Sometimes, inadequate methodologies and a diverse level of ambition in the formulated targets are observed.

Findings – It is found that the INDCs of those 15 countries alone imply the release into the atmosphere of 84 per cent of the GCB for the period 2011-2030, and 40 per cent of the GCB available until the end of the century.

Originality/value – This is the first time the INDCs of the top 15 emitters are analyzed. It is also the first analysis made using the GCB approach. This paper suggests methodological changes in the way that the future NDCs might be formulated.

Keywords Paris agreement, Carbon budget, Cumulative emissions, Global carbon budget, Long-term mitigation goal, NDCs

Paper type Research paper

1. Introduction

One of the main problems on a global scale that humankind is facing nowadays is climate change. From now, and in the coming years, the Paris Agreement (PA) (UN, 2015), which entered into force on November 4, 2016, is destined to play a central role in the multilateral actions against climate change. For this reason, an in-depth analysis of the agreement from scientific, methodological and political perspectives is extremely necessary.

In terms of mitigation, the main objective of the PA is set out in paragraph a of the article 2.1, which is quoted below:

© Olga Alcaraz, Pablo Buenestado, Beatriz Escribano, Bàrbara Sureda, Albert Turon and Josep Xercavins. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial & non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode

The authors want to thank Pepe Antequera, who unfortunately is no longer among us, for the time they spent together.

The research leading to these results has received funding from “la Caixa” Banking Foundation.
Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.

The formulation of a global goal is not new in the policies on mitigation (UNFCCC, 2011), but in the context of the new agreement it is, and will be, the unique real concretion of the mitigation long-term goal.

To achieve this goal, the agreement defines a methodology based on the nationally determined contributions (NDCs). The agreement makes the first and main reference to these NDCs in Article 3. According to this article, the NDCs will be, in practice, the only operational instrument, that will always be in the hands of state-parties from now on and will define the national efforts with a view to achieving the goal of the PA. On the road toward Paris in COP19 and COP20, a call was made for countries to elaborate their intended nationally determined contributions (INDCs) and to send them to the UNFCCC (UNFCCC, 2013, 2014).

According to the package of decisions of the COP21 (UNFCCC, 2015a), this set of INDCs is likely to be the first official set of NDCs in the context of the PA, when the state-parties ratify the agreement (see decision 22). Currently, most countries have already sent their INDC to the UNFCCC, when they ratify the PA mostly they confirm their INDC as their first NDC (only 6 of the first 172 countries that ratified the PA have announced that they will submit a new NDC) (UNFCCC, 2016a, 2016b). This allows very accurate analysis about what these INDCs imply referring to the temperature objective. It should be emphasized that the reports published both before (UNEP, 2015; UNFCCC, 2015b) and after the Paris Summit (UNEP, 2016; UNFCCC, 2016c), present worrying results.

Still considering the methodology established by the PA, another key point is Article 14, where the “global stocktake” is defined as the way to assess the collective progress toward the objectives and the long-term goals of the Agreement. Paragraph 3 of the same article makes it clear that the global stocktake will only be for information purposes for the state-parties (UN, 2015). But it is clear that the global stocktake will be the only reference clearly and objectively showing the real state of the fight against climate change. Therefore, it will provide essential information that will help stakeholders to make any necessary policy changes (always according to their capacities and responsibilities).

According to the decisions 23, 24, 26 and 28 of the COP21, the second set of NDCs will arrive during 2020. And, from now on, the Ad Hoc Working Group on the PA has to elaborate the guidelines for the information to be provided and for accounting of the future NDCs. These guidelines will be considered and approved by the Conference of the Parties serving as the meeting of the Parties to the PA when it finishes its first session, in 2018. This session started in November 2016 in Marrakesh.

In summary, the PA establishes a bottom-up methodology, based on the NDCs that countries should prepare every five years. The UNFCCC, will perform the global stocktake to assess the aggregate effect of these contributions, and how far we are from achieving the target temperature. On November 4, 2016, the agreement entered into force, and we have a first set of INDCs playing, in practice, the role of the first set of NDCs that can be assessed. In addition, before countries begin to prepare the second set of NDCs, it is necessary to establish guidelines for very important aspects of their future structure.

The aim of this paper is to link scientific knowledge to policy proposing a new method that allows scientists and policymakers to monitor whether humankind is progressing adequately toward the goal of keeping the temperature rise below 2°C and also, how far it is from this goal. This method is based on the concept of global carbon budget (GCB), which is discussed and defined below. The authors apply it to study the aggregate effect of the
INDCs presented by the fifteen countries that currently lead the ranking of global emissions. This allows them to focus on the structural format of future NDCs. This format should facilitate objective and easily comparable analyses, of both domestic and global effects, and it should especially facilitate an aggregate assessment.

In accordance with this general objective, the layout of this paper is as follows: in Sections 2 and 3 the concept of GCB is introduced, and it is proposed a definition of GCB specially adapted to policies on climate change mitigation. In Section 4, the authors analyze individually and collectively the INDCs of the 15 countries that are leading the world’s emissions and they determine the percentage of the GCB that these INDCs imply. Finally, in Section 5, the authors discuss the results and make some suggestions concerning the format and the method that the CMA should approve for the future calculation of NDCs. In Section 6, the main conclusions are presented.

2. The global carbon budget concept applied to the objectives of climate change mitigation policies

The concept of GCB is used, often referred to as cumulative emissions, when different future scenarios of emissions are built to foresight the increase of the concentration of CO₂ in the atmosphere and the effect that this increase will have on the Earth’s radiative forcing and on the rise of the planet’s surface mean temperature (Clarke et al., 2007; Riahi et al., 2007).

When considering CO₂, the specialized literature (Frölicher et al., 2013; Herrington and Zickfeld, 2014; Matthews et al., 2009; Zickfeld et al., 2012) and specially the last IPCC report (IPCC, 2014) establish very clearly that cumulative CO₂ emissions are the main agents responsible for global warming and show that the proportional relationship between cumulative CO₂ emissions and the long-term temperature increases.

Although CO₂ is the main gas responsible for global warming of anthropogenic origin, the contribution of other greenhouse gases (GHG) is not negligible. In 2010, the non-CO₂ gas emissions, excluding land-use change and forestry (LULUCF), made up 24.7 per cent of the total CO₂ equivalent (World Resources Institute, 2015). For some years, determining the effect of the non-CO₂ gas emissions accumulated from now until the end of the century has been somewhat controversial because the specific nature and the time it remains in the atmosphere varies for each gas; in other words, their impact on the Earth’s radiative forcing is diverse (Rogelj et al., 2015, 2016). Fortunately, Meinshausen et al., 2009 have shown some light on the relationship between cumulative emissions of a mix of GHG and the probability of keeping the temperature rise below a specific limit. At a practical level, for policy-making, the need to define the GCB for a mix of GHG, i.e. including non-CO₂ gas contributions, has already been recognized (Meinshausen et al., 2009).

In the authors’ opinion and coinciding with other authors (Kanitkar et al., 2013; Peters et al., 2015; Raupach et al., 2014), the concept of GCB can play a key role in the climate change mitigation policies and the definition and quantification of this concept are the main objectives of this study. And so, the authors begin by defining the GCB with respect to mitigation policies. Moreover, they show how this concept can be useful for the methodology accepted in the PA to check how close we are or not to achieving the 2°C goal, defined in the Agreement.

The GCB for CO₂ and also for a combination GHG, is defined as the cumulative emissions of anthropogenic origin permissible from 2011 until the end of this century (2100) to maintain the increase of the average temperature of the Earth’s surface below 2°C. Using the definition of Rogelj et al., 2016 this is an example of a “Threshold avoidance budget”, i.e. a Carbon Budget (CB) that prevents crossing a specific temperature threshold, specifically 2°C. From now on, the authors will use the initials GCB to refer to the total World cumulative emissions and they will use CB to refer to cumulative emissions of one country or a group of countries.
over specific time periods. It is important to mention that the authors propose restricting these terms only to future emission scenarios that are compatible with maintaining the temperature rise below 2°C and therefore the historical emissions have not been included.

It is also important to point out that at the same time it is possible to extend these definitions to scenarios that limit the temperature rise to 1.5°C, and this extension would be called the GCB for 1.5°C (GCB\textsubscript{1.5}). At the moment, it is only possible to quantify this GCB\textsubscript{1.5} for CO\textsubscript{2} (IPCC, 2014), and not for all the GHG. For this reason, these scenarios will not be included in this article, and the authors will wait for the IPCC report on the 1.5°C scenarios that according to the decision 21 of the Paris COP21 (UNFCCC, 2015a) will be published in 2018.

Nowadays, in the literature, a wide range of future emissions scenarios can be found, (Meinshausen et al., 2011; van Vuuren et al., 2011) some of which are compatible with the 2°C goal. One of these is the RCP2.6 scenario (van Vuuren et al., 2011), published in the last IPCC report (IPCC, 2013), which has more than 66 per cent probability of achieving the 2°C goal. The figures from this scenario, for each one of the GHG, are available on the Potsdam Institute for Climate Impact Research database (RCP Scenario data group, 2010) and the authors have used them in this article, both for CO\textsubscript{2} and for all the Kyoto GHG.

In Figure 1, the RCP2.6 scenarios updated to the latest emission records available are shown. The blue shaded area shows the GCB related to these scenarios. It is necessary to point out that the database contains historical records up to 2005, when the future projections start. As we now have historical data up to 2012 (World Resources Institute, 2015), the authors have slightly shifted the original scenario by 0.6 per cent in order ensure the continuity of the emission curve from 2012 to 2013.

In Figure 1(a), the RCP2.6 for only CO\textsubscript{2} emissions produced by the burning of fossil fuels and cement production is shown. In this scenario, the cumulative emissions between 2011 and 2100 amount to 1,000 GtCO\textsubscript{2} (in other words, this is the integral area of the curve between these years). This is the value of the GCB for CO\textsubscript{2}, and it is currently widely accepted by the scientific community (Friedlingstein et al., 2014; Peters et al., 2015).

The quantification of the cumulative CO\textsubscript{2} emissions included in the IPCC AR5 Synthesis Report (IPCC, 2014) is extremely relevant. It shows that, calculating from 1,870, the cumulative CO\textsubscript{2} emissions allowable to reach the 2°C goal, amount to 2,900 [2,550 to 3,150] GtCO\textsubscript{2}. Of these emissions, 1,900 [1,650 to 2,150] GtCO\textsubscript{2} were released before 2011, leaving...
about 1,000 GtCO₂ to emit from 2011 onwards. In summary, in line with the objectives and analysis of this paper, it can be stated that the GCB for CO₂ from 2011 to 2100 is 1,000 GtCO₂. This figure will offer a 66 per cent likelihood that the temperature rise will not go above 2°C with respect to the preindustrial era.

Fortunately, this figure of 1,000 GtCO₂ has finally been included in the evaluations of the aggregate effect of the INDCs carried out in different studies (UNEP, 2015, 2016) and it also appears in the synthesis reports (UNFCCC, 2015b, 2016c) elaborated by the UNFCCC itself. These synthesis reports will ensure that this concept will finally take its place in the political world.

One of the objectives of this paper is to emphasize the importance of incorporating the concept of GCB in mitigation policies and also of the political analysis of their effect. It is also necessary to monitor how the GCB is being spent over the years. A simple look at the curve shown in Figure 1(a) quickly makes us aware that if humankind wants to be faithful to the Paris 2°C goal, it must achieve the end of fossil fuel combustion during this century and ensure that these 1,000 GtCO₂ are the last CO₂ emissions released into the atmosphere.

However, even though CO₂ is the main gas responsible for the greenhouse effect, it is not the only one. Because of this, and taking into account that at the moment nearly all the countries who have presented their INDCs, have included CO₂ along with other GHG (and have not separated the figures for CO₂), it is even more obvious that it is very important to extend the GCB concept, which was initially only used for CO₂, to all the GHG.

In Figure 1(b), the same RCP2.6 scenario for all the GHG included in the Kyoto Protocol is shown, aggregating the different contributions using the AR4 GWP100 (IPCC, 2007). Here, the integral area between 2011 and 2100 amounts to 1,800 GtCO₂eq. Although it is important to be aware that, when non-CO₂ gases are also considered, the relationship between accumulated emissions and temperature rise is, to a certain point debatable (Rogelj et al., 2015, 2016), this figure also fits perfectly with the GCB values for all the GHG that appears in the paper of Meinshausen et al., 2009. According to this paper, and after using straightforward algebra (Appendix), it can be stated that a GCB of 1800 GtCO₂eq involves a probability higher than 62 per cent (ranging between 43 per cent and 81 per cent) that the 2°C limit will not be exceeded. Therefore, the authors think, for both practical and operative reasons that, in a policy-making context, it is important to also identify the integral area of the RCP2.6 scenario curve, with the GCB for all the GHG.

The UNFCCC itself, in its report about the aggregate effect of the INDCs, is already considering, among other factors, the consumption of the CO₂ budget that the INDCs will imply (only CO₂, not other GHG). The main results of this report are worrying, because the aggregate effect of the current INDCs would imply the consumption of 53 per cent of the GCB by 2025 and 74 per cent by 2030 (UNFCCC, 2016c). These are percentages of the total CO₂ GCB available for all the century, i.e. the 1,000 GtCO₂ above mentioned. In other words, if the unconditional commitments expressed by the countries to the UNFCCC are fulfilled, in 2030 we will already have consumed 74 per cent of the CB we have available until the end of the century. Although the UNFCCC uses the concept of GCB in its report, instead of using this term, it uses the term “cumulative emissions”. It is important to point out, that, unfortunately, the concepts of CB and GCB (or cumulative emissions) had not entered the praxis of the UNFCCC before and, consequently, they are not included in the way that countries have formulated their mitigation intentions at the time of elaborating their INDCs, although a few of them have presented their future estimated CB in addition to their mitigation objectives.

This again shows the importance of quantifying and monitoring how this GCB is being consumed and to have this budget as a conceptual and quantified figure of reference.
3. The way the mitigation objectives are presented in the intended nationally determined contributions

When considering mitigation goals, the format of the INDCs is very different. In general, many INDCs express emission reduction targets to be achieved by a given year, but do not specify the pathway they will follow between 2020 and 2030 (or 2025) to achieve this objective. It can be seen that the commitments of countries have not been made based on a method that limits their CB, and would ensure that the GCB is not being exceeded. This is a very worrying fact, confirmed by the reports on the aggregate effect of INDCs that, a posteriori, have attempted to assess the CB that these INDCs imply (Iyer et al., 2015; Peters et al., 2015; UNEP, 2015; UNFCCC, 2015b, 2016c). The situation is also aggravated because between 2012 and 2020, the international community is in a period without legally binding commitments and where the consumption of the GCB is not being controlled. The latest data records reach until 2012, and between 2012 and 2020 mitigation commitments expressed by some countries are voluntary. In the meantime, and with a high likelihood that GHG emissions will increase during this period, the world is waiting for the implementation of the PA.

Figure 2 illustrates the uncertainty regarding the consumption of the GCB in the coming years. Again, it clearly shows that a commitment in terms of percentage of reduction with respect to a certain base year does not imply any commitment regarding the mitigation pathway to be followed by the country. And, as well as this, to assess the CB that it will use, it is necessary to know the detailed mitigation pathway. It is worth mentioning that the CB equals the integral area of the mitigation pathway.

4. Results

In this section, the authors present the analysis of the INDCs (UNFCCC, 2015c) of the 15 countries or aggregates of countries (the EU-28 is treated as a single state party) that had the highest levels of emissions in 2010, and which have been given the name “TOP-15”. These state-parties contribute 79 per cent of total global emissions (World Resources Institute, 2015).

![Figure 2. Example of different possible pathways (in blue dots and green triangles) that fit with the same target (at 2030) and that implies different carbon budgets (areas marked with blue squares and green lines)](image-url)
The rest of the state-parties, responsible for 21 per cent of global emissions, have initially been treated as a single group, which have been given the name “Rest of the world”. Table I includes the most general characteristics of these INDCs regarding the mitigation issue. The diversity of formats in which these INDCs are presented is more than remarkable. Some state-parties (Iran, Mexico and Indonesia) present two mitigation objectives, an unconditional objective and a conditional one that is more ambitious and depends on external factors. In this paper, only the unconditional mitigation objectives have been considered.

It is worth mentioning that the targets of the INDCs of China and India are given in emissions per gross domestic product (GDP). In relation to this point, and to assess what these contributions might represent in terms of emissions, it is necessary to have some foresight into the future GDP of these countries. For this reason, the authors have used the foresight published in the Economic Outlook No 95 - Long-term Baseline Projections, (2014) OECD, (2014). According to this, the GDP of China in 2020 and in 2030 will be, respectively, three and five times the GDP in 2005. And the GDP of India in 2020 and 2030 will be, respectively 2.6 and around 4.6 times the GDP in 2005. It is important to note there is a level of uncertainty in the long-term GDP estimations.

Table II presents the comparison of the unconditional mitigation contributions of each of these countries with respect to the same base year (2010), and also, the emissions per capita of these countries in 2010. The population data were obtained from UNDESA Population Division (UNDESA Population Division, 2015). A good reference point when making assessments of the different countries’ mitigation efforts is emissions per capita. In 2010, GHG emissions per capita in the world were 6.2 tCO₂eq. The red line drawn between China and Mexico separates countries that are above the world average from those that are below.
Table II also indicates the GDP per capita based on purchased power parity (PPP), measured in constant 2011 international USD, for these countries in 2010, according to the World Bank database (The Worldbank Group, 2016). The global GDP per capita PPP that year was 13070 USD2011. Moreover, Table II shows the per capita emissions of each country in 2030 assuming that the mitigation commitments expressed in their INDCs are met.

For the sole purpose of being able to make a comparison between the countries studied and to analyze the aggregate effect of these INDCs, in this paper, the authors have extrapolated China’s commitment (that only refers to CO2 emissions) to all the GHG. They have also extrapolated the United States' commitment (that only refers to the period from 2020 to 2025) between 2026 and 2030, assuming a reduction of 257 MtCO2eq per year in this period. The annual reduction of the USA in the voluntary first commitment period (until 2020) is 61 MtCO2eq per year, and from 2020 to 2025, 159 MtCO2eq per year.

To estimate the CB that these INDCs involve, the unconditional mitigation contributions have been added on to the historical GHG emissions curve of each country. The LULUCF contribution is not included in this study, mainly because of a lack of reliable historical data at a country level, consistent over time. In the case of countries which have stated INDC commitments for 2020, they have been taken into consideration. Then, the authors have drawn linear mitigation pathways between the last year for which they have real data (2012) and the target year (or years). For those countries (e.g. South Africa) that do not indicate a single value but a range, the mid-range value has been used to draw the pathway.

Starting from these traced mitigation pathways, the authors calculate the CB (i.e. the cumulative emissions) for each of these 15 countries between 2011 and 2030. Figure 3 shows,
for the TOP-15, the percentage distribution of 846 GtCO$_2$eq (i.e. the GCB available between 2011 and 2030 according to RCP2.6 scenario) and compares it with the percentage of emissions of these countries at 2010.

A complementary perspective is provided by Figure 4, where the aggregate effect of the mitigation pathways of the TOP-15 countries is presented superimposed on the mitigation RCP2.6 scenario (remember that the integral area under the RCP2.6 curve is the GCB).

5. Discussion

With respect to the INDCs format, the 15 INDCs analyzed are widely diverse. The wide range of formats in which the INDC information is provided makes it difficult to compare them and to assess if we are on track for the 2°C goal.

Figure 3.
(a) Percentage distribution of the GCB available in the period 2011-2030, among the TOP-15 state-parties, according to their INDCs and (b) Percentage distribution of the World emissions among the TOP-15 state-parties at 2010.

Figure 4.
The GHG trajectories of the TOP-15 countries added together, compared with the RCP 2.6 scenario for the aggregated Kyoto GHG.
There is still not an agreement on the base year used by countries in giving their emission reduction percentage. The authors believe it is time to unify this reference year. They think that it could be more convenient to use a relatively recent year and so they have adopted 2010 to compare the different INDCs.

All the countries studied, except the USA, adopted 2030 as the target year. Again, it is time to fix a unique target year.

The set of GHG considered by each INDC is also quite diverse. An extreme case is the case of China, which adopted commitments to reduce only CO$_2$. Another problem is that most countries adopted commitments related to a group of GHG, without specifying the distribution of these commitments for each gas separately.

Several countries give their mitigation commitments as a specified quantity relative to a projected baseline scenario, sometimes referred to as business-as-usual (BAU) targets. Although this method has been suggested in some documents (Levin et al., 2015), the authors think it should only be used as a relative reference for the future trajectory of the country.

In summary, in relation to the formats and contents of NDCs, an important step forward could be made by using very simple guidelines that would unify some important aspects. For example, a common base year, a common set of GHG and the specification of the mitigation pathway that countries will follow during the implementation period. Detailing the mitigation pathway implies determining the CB the countries will use. It is worth noting that the integral area of the mitigation pathway equals the CB (Section 3).

Table II facilitates comparative assessments between mitigation commitments adopted by the countries studied. To assess the level of ambition that these commitments represent, data of both a country’s emissions per capita and GDP per capita PPP for the year 2010 have been included. Emissions per capita can be considered an indicator of the degree of responsibility of countries in relation to climate change. The GDP per capita PPP can be considered as an indicator of the economic capacity of the country to afford mitigation and/or adaptation costs (Baer et al., 2009; Füssel, 2010), and this is not the same as the potential of reducing its emissions. In addition, the last column shows the per capita emissions in 2030 that these countries would achieve if they meet their INDC.

The emissions per capita in 2010 allow a rapid classification of those with per capita emissions well above the world average (6.2 tCO$_2$eq) and those that are below. The former has a higher level of responsibility and would be expected to follow more ambitious mitigation policies. It is remarkable that countries like Saudi Arabia, Russia, Iran and South Africa, with per capita emission levels well above the world average, are still contemplating increasing their level of emissions instead of reducing them. It is interesting to note that Brazil is an example of the opposite, it could increase its emissions per capita but it proposes a reduction. However, the authors must point out that Brazil includes LULUCF in its INDC, and in this paper, LULUCF has not been included. The authors have assumed that the percentage reduction expressed in its INDC would be the same for all sectors, ignoring the fact that the mitigation potential of LULUCF in Brazil is very important (Gebara and Thuault, 2013). This comparison made according to emissions per capita justifies that countries like Indonesia and India, with per capita emissions well below the global average, can increase their level of emissions, although they are currently within the group of 15 countries with a higher level of emissions.

It is also interesting to see what would be the evolution of per capita emissions in these countries at 2030, according to the commitments expressed in their INDCs. In general, we will still be rather far from meeting the figure of 4.3 tCO$_2$eq per capita, which, according to RCP2.6 scenario and the UN DESA population prospects, would correspond to the world carbon budget.
emissions at 2030. Although there are a number of countries that will see a reduction in its emissions per capita, they are still far away from the world average. Saudi Arabia, Russia, Iran and China deserve a special mention as countries that are currently above the world average and their INDCs imply that they will still increase their emissions per capita by 2030. Saudi Arabia, Russia and Iran have a GDP per capita above the world average. In their review about equity and climate change, Mattoo and Subramanian (2012) highlighted the proportional relationship between emissions per capita and GDP per capita as an example of inequity. The fact that the commitment of these three countries implies an increase of their emissions per capita, confirms that we are far from implementing the equity paradigm of the PA.

Among the countries that currently have per capita emissions below the world average, India is the only one whose emissions will almost meet the world average in 2030. Some authors suggest that a good way to include equity criteria in achieving emissions reduction could be that the emission pathways of the different countries converge toward the same number of emissions per capita (Gignac and Matthews, 2015; Meyer, 2000).

Moreover, the GDP per capita PPP can be used to gauge the ability of a country to undertake mitigation policies, which in many cases involve investments in the installation of new technologies, for example for renewable energy production or to achieve a higher degree of energy efficiency (Baer et al., 2007; Mattoo and Subramanian, 2012).

Now, the authors would like to discuss the implications of the INDCs with regard to the global mitigation goals. Figure 3(a) shows what the cumulative emissions, the CB, until 2030 would be, according to the INDC of the 15 countries assessed and compared to the GCB for that period according to RCP2.6. It is worth noting that linear mitigation pathways have been used to calculate the CB, but the actual pathways may not be linear, as discussed in Section 3. Therefore, by assuming linear pathways, the authors are making an optimistic analysis of the consequences of the application of the INDCs.

It is particularly worrying that the commitments of only 15 countries add up to 713 GtCO$_{2eq}$ and represent 84 per cent of the GCB (846 GtCO$_{2eq}$) in 2011-2030 and 40 per cent of the budget for 2011-2100. When the 2011-2030 distribution and the distribution in 2010 are compared [Figure 3(b)], a high degree of coincidence can be seen. In other words, the proposed TOP-15 INDCs are a long way from achieving a turnaround from the current distribution of emissions. As the PA states, this turnaround should be led by the developed countries (article 4.4, UN, 2015), but once again it can be seen that, at least for the moment, the inertia of these countries makes this change very difficult. Several studies highlight the contradiction between ambitious mitigation commitments and the reality (Elzen et al., 2016).

Figure 4 compares the aggregated mitigation pathways of the TOP-15 with the RCP2.6 scenario. This scenario presents a very steep slope of emissions reduction from 2020. It is worth noting that the sum of the mitigation pathways, far from presenting a slope similar to that of the RCP2.6 scenario, remains virtually stable from 2020. This means that the two pathways will almost cross in 2030, which in turn means that from that date, the aggregate trajectory of only 15 countries will exceed the total world RCP2.6 scenario. Among other things, these facts would make the PA worthless from 2030.

6. Conclusions
The PA sets a clear target of mitigation: the global temperature increase must not exceed 2°C. It also defines a methodology for achieving this goal. A bottom-up methodology, based on the NDCs. As some authors suggested (Hermwille et al., 2015) the PA has overcome the old
paradigm of distinct specific targets for developing and developed countries of the annexes of the Convention, and the NDCs goes beyond mitigation targets. In other words, every five years, countries prepare and approve their own mitigation commitments and send them to the UNFCCC. Every five years the UNFCCC will do a study of the aggregated effect of all these commitments, i.e. a global stocktake or global inventory. The global stocktake will be communicated, but in fact only for information purposes, to all the state-parties for them to take it into consideration when elaborating new NDCs (UN, 2015).

Currently, as a result of the process that led to the Paris summit, 190 state-parties have sent their INDCs to the climate convention. These documents, which in principle only express their intentions (not commitments), allow a first assessment about what the aggregate effect represents in relation to the global mitigation goals. In fact, the INDC submitted by each state will become in most cases its first NDC, when the state ratifies the PA, unless it expresses its willingness to change it. Currently, only 6 of the first 172 countries that ratified the PA have announced that they will submit a new NDC (UNFCCC, 2016a, 2016b).

Various analyses of the aggregate effect of these INDCs have been carried out (UNEP, 2015, 2016, UNFCCC, 2015b, 2016c), and everyone agrees that there is a “gap” between the mitigation efforts that countries say they will undertake and the actual effort needed to achieve the objective of 2°C. In addition, different proposals of sharing the efforts of GHG reductions have been published (Herrala and Goel, 2016; Kanitkar et al., 2013; Peters et al., 2015). Unfortunately, the Agreement does not define any binding mechanism for feedback; only a communication to inform the parties about the global balance of the aggregate effect of the NDCs, which will be done every five years.

This article identifies the concept of GCB as a key concept that should be introduced as an obligatory reference for NDCs. In this context and mainly for policy purposes, the authors propose that the GCB for all the GHG can be assessed in a very simple way: by calculating the integral area under the curve of the mitigation scenario RCP2.6 for all the GHG. The GCB obtained between 2011 and 2100 amounts to 1,800 GtCO₂eq. Being aware that the extension of the GCB concept to all the GHG is an issue still under debate, the authors use the Meinshausen et al., 2009 “2°C Check Tool” to verify that the figure of 1,800 GtCO₂eq fits with their estimations. This software verifies that these 1,800 GtCO₂eq will result in a higher than 62 per cent probability (ranging between 43 per cent and 81 per cent) that the 2°C limit will not be exceeded.

The authors have shown that it is highly recommended that countries should formulate future NDCs by specifying the mitigation path over all the years that the NDC applies to. The inclusion of this measure would represent an improvement to the current situation because it implies that countries must unambiguously identify the CB (i.e. the cumulative emissions or the integral area of the mitigation path) that they will use during the total implementation period of their NDC. This framework would also facilitate the assessment of the level of ambition and the overall fairness of each NDC, because it would be possible to compare each NDC with the rate of consumption of the remaining GCB that it represents. Despite all of these, it is necessary to be aware that to guarantee the effectiveness of NDCs, further policy tools are needed. And, even more so to achieve an implementation of the PA in the light of equity. To offer an example, the guidelines of the features of the new NDCs could include the strong recommendation that state-parties should take into account the distribution between them of the GCB based on equity criteria as a reference for elaborating the next and the future NDCs.

In this study, the INDCs submitted by the 15 countries that currently head the ranking of global emissions have been analyzed. From a preliminary analysis, it has been seen that the
INDCs have been elaborated with a wide variety of formats and that efforts to unify them are needed. In addition, a diverse level of ambition in the formulated targets has been observed. These 15 INDCs have been analyzed according to the method proposed in this article. It was found that the commitments of the 15 countries alone imply the release into the atmosphere of 84 per cent of the GCB for this period, and 40 per cent of the GCB is available until the end of the century.

The study also found that the important emission reductions required by the RCP2.6 scenario will not be achieved. This analysis implies that by 2030 it would be impossible for humankind to comply with the only scenario that has a chance of fulfilling the PA. The world is therefore facing an extremely delicate moment with regard to the necessary mitigation policies to be followed if it wants to achieve the 2°C goal. The PA, ratified in November 2016, provides a methodology for progressing toward the target. This methodology will need to incorporate effective instruments to address a situation that today is far from being under control or on the right track. The incorporation of the concept of GCB for both CO₂ and for all the GHGs is very useful when analyzing the aggregate effect of the contributions of the countries. In addition, it could be interesting to incorporate this concept when a new set of NDCs is formulated, clearly identifying the CB (or its percentage within the GCB) that the NDCs imply. This method could be the only guarantee that we still have to change the course we are on and to.

References


Appendix

With the aim of validating the Figure 1(b) and the corresponding quantification of the GCB for all the GHG and also identifying the percentage likelihood that this GCB will meet the 2°C goal, the authors have used the “2°C Check Tool” provided in the additional materials of the paper by Meinshausen et al., 2009. When the accumulated emissions between 2000 and 2049 are introduced into the “2°C Check Tool”, the program calculates the probability that the temperature will rise above 2°C by assessing the probability range using several independent references. To use this tool, the accumulated emissions of the RCP2.6 scenario [Figure 1(b)] between 2000 and 2049 have been calculated, and the result is 1790 GtCO₂eq (423 Gt from 2000 and 2010 + 1367 Gt from 2011 to 2049). When this result is introduced, the tool gives a probability higher than 62 per cent (ranging between 43 per cent and 81 per cent) that the 2°C limit will not be exceeded. Therefore, it is important to also identify the integral area of the RCP2.6 scenario curve, with the GCB for all the GHG. The GCB between 2011 and 2100 amounts to 1800 GtCO₂eq (1367 Gt from 2011 to 2049 + 433 Gt from 2050 to 2100).

Corresponding author
Olga Alcaraz can be contacted at: olga.alcaraz@upc.edu

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: permissions@emeraldinsight.com
Effects of China’s environmental policy on carbon emission efficiency

Xiongfeng Pan, Xianyou Pan, Changyu Li, Jinbo Song and Jing Zhang

Faculty of Management and Economics,
Dalian University of Technology, Dalian, China

Abstract

Purpose – The purpose of this paper is to analyze the effect of environmental policy China’s national program to address climate change on carbon emission efficiency.

Design – Based on the directional distance function, the provincial total factor carbon emission efficiency was measured. Then, the authors analyzed the effect of environmental policy on carbon emission efficiency based on a difference in difference model.

Finding – Carbon emission efficiency has been significantly improved since the environmental policy China’s national program to address climate change was put forwarded, but the positive impact in different periods and regions is different. In addition, the environmental policy improves the carbon emission efficiency through the reduction of energy intensity and adjustment of the industrial structure.

Originality/value – This is the first time to use difference in difference model to use a difference in difference model to quantitatively assess the influence of environmental policy China’s national program to address climate change on carbon emission efficiency.

Keywords Environmental policy, Carbon emission efficiency, Difference in difference method

Paper type Research paper

1. Introduction

Global climate warming caused by the “greenhouse effect” has caught considerable attention worldwide. Recently, urbanization and industrialization have taken a great stride forward in China. Coal is one of the most important supporting elements; the total energy consumption in 2015 amounted to 43 tons of standard coal, which increased by 2.93 times compared to that in 2000. Cheap coal with abundant reserve has become the first choice of resource element considering that the conditions of resource endowment and economic development cost constraints. The Statistical Communique of the 2015 National Economic
and Social Development revealed that the proportion of coal consumption was as high as 64 per cent in 2015. Large-scale exploitation and utilization of coal resources have driven national and local economic development, but it has caused serious environmental problems simultaneously. According to the annual global carbon emission data of 2013 published by the Global Carbon Project, China’s total carbon emission exceeded the summation of European Union (EU) and the USA, wherein the per capita carbon emission reached 7.2 tons and exceeded that of Europe for the first time. Accordingly, the Chinese Government has committed to the reduction of carbon emissions and to the improvement of carbon emission efficiency for a long period. In 2007, the China Development and Reform Commission promulgated the environmental policy China’s national program to address climate change (hereafter referred to as national program). As an essential task of performing climate convention, the national program pointed out the special goals, basic principles, key areas and policy measures. In accordance with the requirements of the scientific concept of development, the Chinese Government implemented various tasks stipulated by the national program earnestly, striving to build a resource-conserving and environment friendly society.

The national program has been implemented for more than 10 years. However, it is uncertain whether the implementation of the national program has improved the carbon emission efficiency and relieved the climate problems. Thus, this study calculated the carbon emission efficiency on the basis of the sample of provincial panel data in China and then evaluated the abatement effect caused by the implementation of the national program. The authors believe that the findings can help to demonstrate the gains and losses of the implementation of the national program. This study provides a theoretical basis for the formulation of environmental policy in the future.

The rest of the paper is organized as follows: Section 2 discusses the relevant literature; empirical methodology is presented in Section 3; Section 4 presents the data; in Section 5, the empirical results and their implications are reported and discussed; finally, Section 6 summarizes the research findings and conclusions.

2. Literature review
2.1 Effect of environmental policy on carbon emission efficiency
Fundamentally, the improvement of carbon emission efficiency reflects the progress of carbon emission reduction technology. A considerable number of useful information from the literature that discussed the relationship between environmental policy and technology innovation can be obtained. A review of the previous studies on the relationship between environmental policy and technology innovation shows inconsistent conclusions. The most direct change is the operating cost caused by environmental degradation when firms are faced with environmental policy. However, different enterprises may have different reflections when dealing with environmental degradation cost. On the one hand, along with the increase in operating cost, enterprise investment scale of other production factors (equipment update, innovation elements) will reduce. As a result, the enterprises face technology constraint or cost effect, which has a negative effect on technology innovation (Martin et al., 2013; List et al., 2003; Greenstone and Gayer, 2009; Taylor, 2012; Lange and Bellas, 2005; Feng et al., 2017). On the other hand, according to the “porter hypothesis” proposed by Porter et al. (1995), the competitive advantage is dependent not only on the game behavior under static standard, which is the environmental policy that increases the carbon emission cost of countries and regions but also on the effective simulation of the technological innovation and production of the innovation compensation effects (Brunnermeier and Cohen, 2003; Popp, 2012; Aghion et al., 2016).
2.2 Policy evaluation

Previous theoretical studies on policy evaluation can be divided into broad sense and narrow sense. The broad sense policy evaluation is aimed at comprehensively evaluating policy implementation process, methods and objects comprehensively. For example, Lasswell (1951) introduced the concept of broad sense policy evaluation as a statement of the causation. Contrary to broad sense policy evaluation, the narrow sense policy evaluation was in favor of judging the value, performance, and efficiency. Charles (1984) pointed out that the policy evaluation was used to explain, examine and analyze the effect after policy implementation. The role of policy evaluation is related to the gains and losses of policy implementation. Similarly, Nachmias and Nachmias (1976) and Dye (1995) believed that policy evaluation is an objective and systematic testing, which confirms whether the policy implementation has achieved the desired goal.

The empirical analysis methods of narrow sense policy evaluation are mainly categorized into three types: social indicator, multiple attribute effect analysis and policy experiment. The social indicator method judges the policy effect on the basis of the change of social indicators before and after policy implementation (Nachmias and Nachmias, 1979; Lehrman, 2013). This method is simple and direct but lacks stringency and scientific support. Thus, it does not have a significant advantage in the field of policy evaluation. The multiple attribute effect analysis method segments the indicators into various levels such as policy implementation process and output end and then evaluates the effectiveness of policy implementation (Edwards and Newman, 1982; Lazarides and Drimpetas, 2011). Contrary to the aforementioned methods, the policy experiment method judges the policy effect through comparing of the change of tendency in different groups before and after policy implementation. In accordance with the principle of policy experiment method, the model of difference in difference (DID) has been widely developed and used (Petrick and Zier, 2011; Piracha and Zhu, 2012; Deschacht and Goeman, 2015; Adan and Fuerst, 2015; Sunak and Madlener, 2016; Winkey, 2017; Hosken et al., 2018).

In summary, the literature has laid a solid foundation for the study on the effect of environmental policy on technology innovation, and provides a reference for policy evaluation. However, few scholars have studied the influence of environmental policy on the carbon emission efficiency. To realize the sustainable development of economy and society, this study takes the national program as an example and uses the DID method to test the influence of environmental policy on the carbon emission efficiency in accordance with the provincial panel data. In comparison with the present literatures, the contribution of this work mainly covers the following aspects:

First, on the basis of the national program proposed by the Chinese Government in 2007 that encountered various problems in the implementation process, such as the lack of execution rigidity, planning lag and region-oriented differences, the authors estimate the total factor carbon emission efficiency of 30 provinces in China in accordance with the directional distance function, discuss the reduction effect of the environmental policy national program implementation and present an in-depth analysis of the mechanism of improving the total factor carbon emission efficiency.

Second, this study tests the relationship between the environmental policy and the carbon emission efficiency in accordance with the DID model. This model can effectively exclude the factors that influence both the environmental policy implementation and carbon emission efficiency, deal with the problem of endogeneity and assess the effect of environmental policy on the carbon emission efficiency effectively.

Finally, this study finds that the carbon emission efficiency has been improved significantly since the national program was implemented in 2007. In addition, the national
can improve the carbon emission efficiency through reducing energy intensity and accelerating the upgradation of industrial structure. However, the influence of economic growth rate on the carbon emission efficiency is relatively weak.

3. Methodology

3.1 Total factor carbon emission efficiency

Various indicators have been developed and applied to demonstrate the carbon emission efficiency. For instance, Kaya and Yokobori (1993) suggested the concept of carbon productivity [the level of carbon emissions per unit of gross domestic product (GDP)]. Tol et al. (2009) showed that both carbon emission intensity and per capita carbon emissions can be considered as useful indicators. The aforementioned indicators were easy to calculate, but they may be interpreted as partial indicators because they can only reflect partial aspects of carbon emission performance. Hence, an increasing number of scholars added the relevant indicators, such as energy consumption, economic activity and carbon emissions into an overall index, evaluated the carbon emission efficiency (Charnes et al., 1978) on the basis of the data envelopment analysis (DEA). The basic idea of measuring technical inefficiency by DEA is to compare the distance between the production unit and the optimal production frontier (Ali and Yang, 2016). In this study, the authors measure the provincial total factor carbon emission efficiency in accordance with the directional distance function, and this model can satisfy the common desire of the public and policymakers to reduce inputs/undesirable outputs and increase desirable outputs simultaneously. The model allows the adjustment of the desirable outputs and inputs/undesirable outputs at different rates on the basis of different vector directions for input–output variables and provides a common framework for deriving the required models by changing the direction vectors (Meng et al., 2016).

Consistent with the definition of environmental technology sets proposed, Chung and Fare assume that there are M countries (M decision-making Units, DMUs), and each country uses three kinds of inputs (X), namely, capital, labor and energy. The three inputs can produce one desirable output gross domestic production (Y) and one undesirable output CO₂ emissions (Yb). The production technology set (T) is expressed as equation (1):

$$T = \{ (X, Y^g, Y^b) : X \text{ can produce } (Y^g, Y^b) \}$$  \hspace{1cm} (1)

On this basis, the directional distance function is defined as (Gomez et al., 2014):

$$D_T = (X, Y^g, Y^b; d) = \sup \{ \delta : (Y^g + \delta \delta^e, Y^b - \delta \delta^b) \in p(X - \delta \delta^X) \}$$  \hspace{1cm} (2)

where \(d = (-d^e, d^g, -d^b)\). The value of \(\delta\) measures the productive technical inefficiency and equation (2) seeks for the maximum attainable expansion of desirable outputs in the \(\delta^e\) direction and the largest feasible contraction of undesirable outputs and inputs in \(d^b\) and \(d^X\) directions. The directional distance function of equation (2) can be evaluated by the following optimization model (taking \(j_0\) as a reference unit):

$$\max_{\delta, d} \delta$$

s.t. \(\sum_{j=1}^{n} \lambda Y^g_{j} - \delta d^e_{j} \geq Y^g_{j0}, \quad r = 1, \ldots, q\)

Carbon emission efficiency
In this study, the authors adopt a direction vector $d=(0, d^g, -d^b)$ that allows for an expansion of desirable factors and a contraction of undesirable ones without increasing the inputs. The value $d^g$ measures the productive technical inefficiency and equation (2) seeks for the maximum attainable expansion of desirable outputs in the $d^g$ direction and the largest feasible contraction of undesirable outputs in the $-d^b$ direction. In addition, the aforementioned model separates the units to efficiency and non-efficiency, but can not rank the efficiency units. To avoid this defect, the authors introduced the super efficiency model proposed by Tone (2001), and the effective production units are ranked again.

3.2 Method for policy evaluation
The DID method has become widespread in estimating causal relationships since the work by Ashenfelter and Card (1985). On his basis, observations were collected for two groups and for two periods. As shown in Figure 1, the treatment group was exposed to the treatment in one period ($t_0$ to $t_1$) and the control group receives no treatment during both periods. The double differences, commonly known as DID method, removed biases in the second period comparison between the treatment group and the control group, which can be the result of permanent differences between those groups, as well as biases from comparison over time in the treatment group, which can be the result of time trends unrelated to the treatment (policy effect) (Abadie, 2005; Finkelstein, 2002; Card and Krueger, 1994).

Figure 1. DID method
Of note, the DID model strongly relied on the assumption that the treatment and control groups follow the same trend over time in the absence of the treatment (Meyer, 1995). However, the national program is a national test, and it is essential to determine the construction of the appropriate control group. To satisfy the conditions of the control and treatment groups close to nature, this study referred to the method of Ouyang and Huang (2013) and predicted the data after policy implementation on the basis of the data before environmental policy implementation. In the prediction process, we used the exponential smoothing method, which is a special kind of weighted moving average method and further strengthened the effect of recent observation on the predicted value (Ge et al., 2013). Furthermore, the predicted value was regarded as the group that is not affected by the policy.

On this basis, this study builds a dynamic model to judge the effect of environmental policy on total factor carbon emission efficiency.

\[
CE_{i,t} = \alpha_0 + \alpha_1 CE_{i,t-1} + \beta_1 X + \delta_1 d_{2007} + \delta_2 d_{\text{promote}} + \delta_3 d_{2007} \cdot d_{\text{promote}} + e_{i,t}
\]

(4)

where \(i\) and \(t\) represent the different regions and years, respectively, and \(CE_{i,t}\) is the total factor carbon emission efficiency. Considering the lagging effect of the carbon emission efficiency, the authors added the lag item \(CE_{i,t-1}\) to the right of the equation. Moreover, as the national program was implemented in 2007, the time variable was defined as \(d_{2007}\); if the time denotes the year before 2007, \(d_{2007}\) equals zero; otherwise, \(d_{2007}\) equals one. \(d_{\text{promote}}\) is the dummy variable of the groups; if \(d_{\text{promote}}\) equals one, it represents the treatment group, and if \(d_{\text{promote}}\) equals zero, it represents the control group. \(\delta_3\) is the key coefficient of regression to be estimated; the value of the coefficient directly reflects the effects of the policy. \(X\) represents the other factors that affect the carbon emission efficiency. The authors reviewed the literature on carbon emission efficiency influencing factors and selected the level of economic development (RGDP), industrial structure (STR) and energy intensity (EI) as control variables (Liu et al., 2017; Goh et al., 2018).

4. Data
According to geographical location and political classifications, China is divided into three parts (eastern, central and western)\([1]\), including 30 provinces, autonomous regions, and municipalities in the mainland of China excluding Hong Kong, Macau, Taiwan and Tibet. The sample period is from 2000 to 2014 and all data are collected from China Energy Statistics Yearbook, China Labor Statistics Yearbook and Data Compilation of Electric Power Statistics.

(1) In the evaluation of the total factor carbon emission efficiency, the authors use the annual data of capital stock, labor and energy consumption as the three input variables, GDP as the desirable output, and \(CO_2\) as the undesirable output. Specific variables are defined as follows:

- The capital stock. This study adopts the “perpetual inventory method” to calculate the actual annual capital stock of each province (Shan, 2008). The formula is \(K_{i,t} = (1 - \delta_{i,t})K_{i,t-1} + I_{i,t}\), where \(K_{i,t}\) is the capital stock in the \(t^{th}\) year of province \(i\), \(I_{i,t}\) is the investment in the \(t^{th}\) year of province \(i\) and \(\delta_{i,t}\) is the depreciation rate in the \(t^{th}\) year of province \(i\) (9.6 per cent). Year of 2000 is used as the base period for the conversion of the actual data with unit of 100m yuan.
Labor. In this study, the year-end employee number of each province is used to express Labor $L$, and the unit is 10,000 people.

Total energy consumption ($E$). This study takes the annual total energy consumption of each province to describe the total energy consumption, and the unit is 10,000 ton standard coal.

Desirable output. The actual GDP in the year 2000 is used as the base period, and the unit is 100 million yuan.

Undesirable output. There was no official statement that announced the annual carbon emission amount of all provinces in China. However, various statistical methods of carbon emissions have already been presented by other scholars (Kaya, 1989; Zhou and Zhou, 2007). Carbon emissions are mainly generated from the combustion of fossil energy. Therefore, carbon emissions from each energy input can be estimated through multiplying the consumption of individual fossil energy input by its carbon emission coefficient (Li and Hu, 2012). The details are as follows:

$$EC = \sum_{i=1}^{7} EC_i = \sum_{i=1}^{7} (E_i - RME_i \times CFR_i) \times CF_i \times CC_i \times COF_i \times 3.67$$

where $EC$ represents carbon emissions ($10^4$ ton) of DMU$_j$ ($j=1, 2, \ldots, n$); 3.67 is the conversion coefficient between carbon and carbon dioxide; $i$ is the index of different types of fossil energies (that is, $i$=coal, coke, petrol, kerosene, diesel oil, fuel oil and natural gas total of 7 species); $E_i$ represents the consumption of fossil energy $i$ measured by $10^4$ ton of standard coal equivalent; $RME_i$ is the amount of energy consumption used as raw material; $CFR_i$ is the carbon fixation rate; $CF_i$ is the calorific value; $CC_i$ is the carbon content; and $COF_i$ is the oxidation factor. The exact value was derived from The 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

(2) Control Variables ($X$):

- The real GDP per capita ($RGDP$) is used to measure the regional economic development, and the unit is 10,000 yuan;
- The ratio of the tertiary industry and the secondary industry output ($STR$) is used to represent the industrial structure index and rating in per cent;
- The ratio of the energy consumption and real GDP ($EI$) is used to represent the energy consumption intensity and the unit is ton standard coal/ten thousand yuan. Table I shows the descriptive statistics for the aforementioned variables.

5. Empirical results

5.1 Measuring regional total factor carbon emission efficiency
This section calculates the total factor carbon emission efficiency of China’s 30 provinces from 2000 to 2014 using MaxDEA software. The results are presented in Figures 2 and 3.

<table>
<thead>
<tr>
<th>Variable (Unit)</th>
<th>Obs</th>
<th>Mean</th>
<th>Std.Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE (C)</td>
<td>450</td>
<td>0.766</td>
<td>0.207</td>
<td>0.118</td>
<td>1.208</td>
</tr>
<tr>
<td>RGDP (Ten thousand yuan)</td>
<td>450</td>
<td>1.891</td>
<td>1.397</td>
<td>0.265</td>
<td>7.890</td>
</tr>
<tr>
<td>STR (%)</td>
<td>450</td>
<td>0.899</td>
<td>0.418</td>
<td>0.494</td>
<td>3.658</td>
</tr>
<tr>
<td>EI (ton standard/ten thousand yuan)</td>
<td>450</td>
<td>1.753</td>
<td>1.070</td>
<td>0.608</td>
<td>5.753</td>
</tr>
</tbody>
</table>
The total factor carbon emission efficiency is different among different provinces. The lowest values are from Shanxi (0.28), Inner Mongolia (0.42), Liaoning (0.47) and Ningxia (0.49), and these values were less than half of the values in efficient units, such as those for Guangdong and Beijing, where the efficiency value was the highest with an average value of 1.01 and 1.04, respectively.

Figure 3 shows the trend of the carbon emission efficiency in three major regions and nationwide during the period 2000 to 2014. The level of the national carbon emission efficiency was fluctuant, and the average was about 0.77. In 2004, the national carbon emission efficiency reached the peak point (0.83), but during the period 2005 to 2008, the value of efficiency decreased by 6.8 per cent. After 2008, the carbon emission efficiency recovered, but the upward trend did not last for a long time; the carbon emission efficiency decreased slightly again after 2011. During the sample period, the average of the carbon emission efficiency in the eastern region was the highest, followed by the central and western regions. The reasons for this difference may be related to the geographical location and industrial structure. On the one hand, most provinces with higher carbon emission efficiency that located in the eastern coastal areas can get better support (Pan et al., 2015), such as capital, technology and information, than the inland areas due to their geographic advantages. To a certain extent, the spatiotemporal distance between the inland and coastal regions hinders the entry of capital, technology and information, which makes the carbon emission efficiency in inland areas remain at a lower level. On the other hand, most regions with higher carbon emission efficiency have a higher level of industrial structure and better market development than other regions. Since the reform and opening up, the southeastern coastal areas, such as Guangdong, Zhejiang and Shanghai, have implemented the “walking out” strategy. With the development of an export-oriented economy, these regions realize the
adjustment and optimization of the industrial structure. Relying on the highly standardized market economy, they transformed the model of extensive economic growth depending purely on the input of resources into intensive ones and developed an industrial structure mainly comprising the service and high-tech industries. However, the industrial development of the central and western regions is low, and the industrial structure is mainly composed of traditional resource-based industries (Zhang et al., 2017).

A comparative analysis of the carbon emission efficiency average in the three major regions shows that the carbon emission efficiency in the central region follows an upward trend after 2007. In the eastern region, the level of upward trend is smaller than that of the central region, but in the western region, the carbon emission efficiency maintains a downward trend. Thus, the authors conducted a preliminary judgment. Considering the difference of economic development stage and economic structure among various regions, the effect of the national program implementation on the carbon emission efficiency may be distinct.

5.2 Effect evaluation of national program implementation

We empirically analyzed the effect of the national program on the carbon emission efficiency in accordance with the System Generalized Method of Moments estimator proposed by Arellano and Bover (1995) and Blundell and Bond (1998) using the software Stata 13.0. To distinguish the difference between different periods, the sample data are divided into two groups by the Twelfth five-year planning. One group is from 2000 to 2010, and the other group is from 2000 to 2014. Furthermore, the difference of the carbon emission efficiency among the three major regions in China is colossal. Meanwhile, the carbon emission efficiency in the eastern and central regions was improved in various degrees, but the upward trend in the western region is inapparent in the year 2007. Thus, we test the effect of environmental policy on the carbon emission efficiency in different regions. The results are shown in Table II.

(1) To illustrate that the system generalized method of moments (GMM) model constructed in this study is reasonable and advantageous, the authors present the regression results based on the traditional OLS model. As shown in the second column of Table II, the coefficients of \(d_{2007} \times d_{promote}\) do not pass the significance test, which implies that the traditional OLS model is not suitable to get an ideal result because of the existence of the carbon emission efficiency lag item.

(2) According to the AR and Hansen test results listed in the last three rows of Table II, the results of AR(2) prove that the null hypothesis is accepted at the 10 per cent significance level. Moreover, the values of the Hansen test are 1.000, which implies that the instrument variables are available. All regression coefficients of \(L.\ CE\) are in the interval [0 1], and pass the significance test at the 1 per cent level.

(3) The coefficients of \(d_{2007} \times d_{promote}\) directly reflect the effect of the national program on the carbon emission efficiency. The regression coefficients of \(d_{2007} \times d_{promote}\) in the two periods are greater than 0 and pass the significance test. Hence, the implementation of the national program has a significant positive effect on improving the carbon emission efficiency. Of note, the regression coefficient (0.264) in the 2000-2014 period is greater than that in 2000-2010 (0.127), which means that the regression result is steady in time dimension. Furthermore, the difference between the two regression coefficients reflects the fact that the implementation of the national program enhances the carbon emission efficiency effectively. However, the effect caused by the implementation of the national program is more
<table>
<thead>
<tr>
<th>Variables</th>
<th>OLS</th>
<th>2000-2014</th>
<th>2000-2010</th>
<th>Eastern region</th>
<th>Central region</th>
<th>Western region</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.CE</td>
<td>0.780 (40.15)***</td>
<td>0.724 (14.05)***</td>
<td>0.740 (14.63)***</td>
<td>0.795 (10.09)***</td>
<td>0.672 (12.36)***</td>
<td>0.724 (44.30)***</td>
</tr>
<tr>
<td>RGDP</td>
<td>-0.001 (0.23)</td>
<td>0.001 (0.17)</td>
<td>0.007 (0.92)</td>
<td>-0.001 (0.18)</td>
<td>-0.015 (0.79)</td>
<td>-0.028 (2.79)***</td>
</tr>
<tr>
<td>EIT</td>
<td>-0.028 (3.17)***</td>
<td>-0.028 (3.08)***</td>
<td>-0.025 (3.31)***</td>
<td>-0.044 (1.32)</td>
<td>-0.054 (4.79)***</td>
<td>-0.028 (8.86)***</td>
</tr>
<tr>
<td>STR</td>
<td>0.029 (3.79)***</td>
<td>0.036 (2.12)**</td>
<td>0.026 (1.59)</td>
<td>0.033 (3.24)***</td>
<td>0.019 (0.32)</td>
<td>0.061 (4.13)***</td>
</tr>
<tr>
<td>dpromote</td>
<td>5.37e-17 (0.00)</td>
<td>-0.300 (-1.65)**</td>
<td>-0.156 (-1.86)*</td>
<td>-0.170 (-1.38)</td>
<td>-0.169 (-2.30)**</td>
<td>-0.010 (-4.13)</td>
</tr>
<tr>
<td>d2007</td>
<td>-0.039 (-4.26)***</td>
<td>-0.174 (-1.97)**</td>
<td>-0.100 (-2.78)***</td>
<td>-0.100 (-1.78)*</td>
<td>-0.113 (-2.45)**</td>
<td>-0.045 (-1.00)</td>
</tr>
<tr>
<td>d2007* dpromote</td>
<td>-0.003 (-0.25)</td>
<td>0.264 (1.62)</td>
<td>0.127 (1.90)</td>
<td>0.140 (1.32)</td>
<td>0.151 (2.22)**</td>
<td>0.013 (0.15)</td>
</tr>
<tr>
<td>c</td>
<td>0.221 (10.46)***</td>
<td>0.405 (3.65)***</td>
<td>0.318 (4.91)***</td>
<td>0.302 (2.78)***</td>
<td>0.457 (5.05)***</td>
<td>0.404 (8.51)***</td>
</tr>
<tr>
<td>Observations</td>
<td>840</td>
<td>840</td>
<td>600</td>
<td>336</td>
<td>252</td>
<td>252</td>
</tr>
<tr>
<td>AR (1)</td>
<td>-5.07 (0.00)</td>
<td>-5.02 (0.00)</td>
<td>-3.68 (0.00)</td>
<td>-2.99 (0.003)</td>
<td>-3.16 (0.002)</td>
<td></td>
</tr>
<tr>
<td>AR (2)</td>
<td>1.25 (0.210)</td>
<td>1.50 (0.134)</td>
<td>0.06 (0.954)</td>
<td>1.65 (0.295)</td>
<td>1.33 (0.184)</td>
<td></td>
</tr>
<tr>
<td>Hansen test</td>
<td>57.67 (1.000)</td>
<td>58.28 (1.000)</td>
<td>20.10 (1.000)</td>
<td>14.39 (1.000)</td>
<td>11.44 (1.000)</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** (1) The figures in parentheses close to the parameter estimates are t-statistics; (2) The figures in parentheses of AR test and Hansen test are probability; (3) ***, ** and * denote rejection of the null hypothesis at the 1, 5 and 10% levels, respectively.
outstanding in the long run. Therefore, to promote the process of energy saving and emission reduction through environmental policy, the government needs to take a long-term perspective.

(4) All the regression coefficients of $d_{2007} \times d_{promote}$ in China’s three major regions are greater than 0. However, the regression coefficients in the central region passed the significance test of the 5 per cent level, and those of the eastern region and western region do not. This result means that the effects of the national program on the carbon emission efficiency among different regions varied. After 2007, the national program has an obvious promotion effect on the carbon emission efficiency in the central region, but the upward trend in the western region is not. Furthermore, considering all factors, the carbon emission efficiency in the western region even shows a downward trend.

(5) The regression results of the control variables are also presented in Table II.

- The effect of economic development on the carbon emission efficiency is not significant on the national scale, but a 1 per cent improvement on the regional economic development will reduce the level of the carbon emission efficiency by 2.8 per cent in the western region.
- The adjustment of industrial structure has a positive impact on the carbon emission efficiency. The positive effect of adjusting the industrial structure on improving the carbon emission efficiency is significant in the eastern region. However, the pillar industry of the economic development has not been effectively established in the western region. The adjustment of industrial structure exerts an inhibiting effect on improving the carbon emission efficiency.
- Energy consumption is a main source of carbon emissions; thus, energy intensity dramatically inhibits the improvement of the carbon emission efficiency. In the central and western regions, a 1 per cent reduction of energy intensity will improve the carbon emission efficiency by 5.4 and 2.8 per cent, respectively.

5.3 Empirical test of the driving mechanism

To clarify the influence mechanism of environmental policy on the carbon emission efficiency, this section discusses the concept from the aspects of energy intensity, industrial restructuring, and economic development. The results are shown in Table III. Of note, the results were calculated using the actual average growth rate of each variable.

First, in terms of energy intensity, the DID result is $-0.8$ per cent. Specifically, the energy intensity in the two groups decreases after 2007, but the energy intensity in the treatment group decreased by 4.78 per cent, which is higher than control group. It can be concluded that the environmental policy has an effective decreasing effect on the energy intensity, thereby improving the carbon emission efficiency. On the basis of the existing conclusions about the effect of energy intensity on the carbon emission efficiency (Table II), the authors find that the effect of energy intensity on the carbon emission efficiency is the most

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment group 2000-2006</th>
<th>Treatment group 2007-2014</th>
<th>$\triangle I$</th>
<th>Control group 2000-2006</th>
<th>Control group 2007-2014</th>
<th>$\triangle I$</th>
<th>$\triangle I - \triangle I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>EI</td>
<td>0.00022</td>
<td>-0.04782</td>
<td>-0.04805</td>
<td>0.00022</td>
<td>-0.03954</td>
<td>-0.03976</td>
<td>-0.00829</td>
</tr>
<tr>
<td>STR</td>
<td>-0.00228</td>
<td>0.02445</td>
<td>0.02674</td>
<td>-0.00228</td>
<td>0.01814</td>
<td>0.02043</td>
<td>0.00631</td>
</tr>
<tr>
<td>RGDP</td>
<td>0.11154</td>
<td>0.10305</td>
<td>-0.0085</td>
<td>0.11154</td>
<td>0.10368</td>
<td>-0.00786</td>
<td>-0.00635</td>
</tr>
</tbody>
</table>
significant in the central region, followed by the western region, whereas in the eastern region, it is statistically insignificant. Therefore, we point out that the environmental policy improves the carbon emission efficiency by lowering energy intensity in the central region, but the effect is relatively weak in the eastern region.

Second, from the perspective of industrial restructuring, the DID result is 0.6 per cent, which implies that the implementation of the national program has effectively sped up the progress in industrial restructuring, and the “Suppress the Second Industry and Develop the Third Industry” policy has improved the carbon emission efficiency effectively. On the basis of the effect of industrial structure adjustment on the carbon emission efficiency in the three regions, the authors can conclude that the implementation of the national program generates positive effects on improving the carbon emission efficiency through boosting the process of industrial structure adjustment in the eastern region, while it generates negative ones in the western region.

Finally, from the perspective of economic development, the implementation of the national program slows down economic growth. In particular, as China entered into a new normal age, the government concentrated on industrial structure adjustment and development with low carbon emission. However, the underdeveloped regions, such as the western regions, try to catch up with the better-developed regions based on the consumption of energy resources, thereby possibly expanding the gap of the carbon emission efficiency among different regions.

6. Conclusions
Improving the carbon emission efficiency by implementing environmental policy is helpful to build an ecologically civilized society when faced with energy and environmental constraints. The national program is one of the important guiding policies for easing carbon emission problem. The total factor carbon emission efficiency of 30 provinces from 2000 to 2014 was calculated using the directional distance function. A DID model was constructed to analyze the emission reduction effect since the implementation of the national program in 2007 objectively. The results are as follows:

First, the carbon emission efficiency was 0.766 on average, fluctuated in different years, and was significantly different among the three major regions in China. As the environmental policy was implemented in 2007, the carbon emission efficiency has been significantly improved, and the positive effect in different periods varied. Furthermore, improving the carbon emission efficiency caused by the implementation of the national program in the central region was essential, but the effects are insignificant in the eastern and western regions. Second, the environmental policy improves the carbon emission efficiency through the reduction of energy intensity and adjustment of the industrial structure, but the influence of economic growth rate on the carbon emission efficiency is relatively weak. On this basis, this study offers some useful policy recommendations.

(1) At present, the development of economy in China depends on the input of energy resources, and carbon emission will continue to grow in the future for a long period. Reducing energy intensity is an effective way of improving the carbon emission efficiency, and this strategy needs to be closely monitored by the government. In addition, renewable energy is essential to improve the carbon emission efficiency, but currently, the proportion is relatively small in China. Thus, the development of renewable energy should satisfy the new demand first, and the replacement of the fossil fuels will follow subsequently.

(2) In China, high-energy consuming industries still account for a major proportion, and the output of the second industries constitutes nearly 40 per cent of GDP. Economic development highly depends on energy consumption. In addition to
emphasizing on the economic reform on supply-side, the government should adopt an adjustment measure for industrial structure upgrading, eliminate parts of energy-intensive industries and fully control carbon emission on the demand side.

(3) The key to developing an ecological and low-carbon economy is to transform the government’s development concepts. According to the development idea of “Green, Recyclable, and Low-carbon” implemented in the 18th National Congress of the Communist Party of China, the government at all levels should strike a balance between economic interests and environment degradation, change the energy consumption pattern and economic development mode and stress on the responsibility system of energy conservation and carbon emission reduction.

(4) Considering the different economic development stages, industrial structure, technology innovation and policy guidance in different regions, the challenges for different regions to reduce carbon emission are different under the drive of a unitary policy. Thus, the implementation of environmental policies is supposed to avoid the “one size fits all” phenomenon. The local governments should take their own economic foundations and advantages into consideration and adjust policy practices timely and effectively.

Note
1. Regional division: following the traditional method, China is divided into the East, Central and West regions. The East includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan; The Central includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan; and the West includes Sichuan, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi and Inner Mongolia.

References


Further reading


Corresponding author

Xianyou Pan can be contacted at: pxybetter@163.com

For instructions on how to order reprints of this article, please visit our website: www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: permissions@emeraldinsight.com
Who is quitting? An analysis of the dis-adoption of climate smart sorghum varieties in Tanzania

Franklin Simtowe
International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya, and
Kai Mausch
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Nairobi, Kenya

Abstract
Purpose – New agricultural technologies are continuously generated and promoted for adoption by farmers with the expectation that they bring about higher benefits than older technologies. Yet, depending on the perceived benefits, the user of the technology may choose to stop using it. This paper aims to analyze what drives farmers to dis-adopt climate smart sorghum varieties in Tanzania.

Design/methodology/approach – The study uses cross-sectional farm household level data collected in Tanzania from a sample of 767 households. The determinants of dis-adoption are explored using a bivariate probit with sample selection model.

Findings – The authors find that while farmers switch between different sorghum varieties, most farmers actually quit sorghum production. Older farmers and those facing biotic stresses such attacks by birds are more likely to dis-adopt sorghum.

Practical implications – These findings suggest that there is scope for improving and sustaining the adoption of sorghum varieties in Tanzania once extension services are strengthened. The findings also point to a well-founded theory on the role of markets in enhancing the overall sustainability of food systems.

Social implications – The study findings have broader implications for understanding the sustainability of improved technology adoption

Originality/value – Dis-adoption is also positively associated with the lack of access to markets underscoring the role of markets in enhancing the overall sustainability of technology adoption and food systems.

Keywords Sorghum, Tanzania, Bivariate selection, Dis-adoption

Paper type Research paper

JEL classification – O33, Q12, Q16.
© Franklin Simtowe and Kai Mausch. Published in International Journal of Climate Change Strategies and Management. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode

This work was undertaken as part of, and funded by the CGIAR Research Program on Grain Legumes and Dryland Cereals (GLDC). Funding support for this study was provided by the Bill and Melinda Gates foundation.
1. Background 

1.1 Motivation

With over 40 per cent of the area classified as arid, food insecurity in sub Saharan Africa (SSA) is wide spread and dire. Climate change predictions for SSA suggest rainfall reduction, variable distribution pattern, increased erratic rainfall, intra-seasonal dry spells and incidences of flooding, high temperatures and higher frequency of droughts (Hadebe et al., 2016). There is scope for mitigating the negative impacts of climate change on food security through the development and dissemination of crops with a high ability to withstand water-stress periods. Sorghum’s drought, heat and flooding tolerance (Hadebe et al., 2016), and the ease of adoption by farmers makes it an ideal crop for production in SSA. Ex ante impact assessments have also shown that, in fact, climate change will create more favorable growing conditions for sorghum (Orr et al., 2016) as compared to maize. According to this study, sorghum will remain an important food crop within the SSA region, particularly in drought-prone areas where household food security cannot rely solely on maize. Sorghum’s resilience to drought will increase its importance as a source of adaptation to climate change.

In Eastern and Central Africa, sorghum is a major food security crop accounting for 41 per cent of the region’s grain production (Msongaleli et al., 2004). Orr et al. (2016) report that smallholders in Tanzania grow sorghum primarily as a food crop, responding slowly to changes in relative market prices compared to maize, but reducing the production of sorghum after a year of good rains when they had experienced a bumper harvest of maize. In addition to food and feed, it is used for a wide range of industrial purposes, including starch for fermentation and bio-energy as well as feed for livestock.

Despite its strategic importance, sorghum yields are low, averaging approximately 1000 kg ha\(^{-1}\) which has been broadly attributed to low soil fertility, bird feeding damage, striga, weed infestation, use of cultivars with low yield potentials and other socio-economic factors (Msongaleli et al., 2004). Resulting from increased efforts by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the National Agricultural Research Institutes, several improved sorghum varieties have been released in the past four decades (Ndjeunga et al., 2015). While such varieties offer great promise for boosting sorghum productivity and better resistance to biotic and abiotic stresses, Schipmann et al. (2013) report that their adoption remains dismal and their adoption dynamics have not been fully understood. However, as expressed by Sanou et al. (2017), while the low technology adoption rates in the developing world may be attributed to dis-adoptation (farmers who once adopted a new technology but have stopped using it), only a few studies have focused on factors affecting continuous or discontinuous use of adopted technologies, with the exception of Oladele (2005), Neill and Lee (2001) and Kim (2017).

The extent to which sorghum variety abandonment or switching is happening among sorghum farmers in Tanzania has never been fully understood. The question addressed in this study is:

In the light of the prominence of wide spread dissemination of improved sorghum varieties in Tanzania, are some varieties being adopted and then dis-adopted? If yes, what does the adoption and subsequent dis-adoptation of such varieties tell us about the sustainability of sorghum production in Tanzania and the resulting lessons for sorghum breeders, policy makers and farmers?

The factors to explain adoption and dis-adopt cycles may be external, agronomic and climatological factors, or internal to the sorghum system and are the main focus of this study.
1.2 The sorghum sector and its importance in Tanzania

Tanzania is the largest producer of sorghum in Eastern and Southern Africa, occupying 21 per cent of the total cereal area in the country (Brown, 2013). It is the third most cultivated cereal after maize and rice, and it is mostly grown in the central parts (Figure 1). According to Ashimogo (1995), 90 per cent of sorghum producing households consumed the sorghum they produced.

According to the United Republic of Tanzania (2012), Singida, Shinyanga and Dodoma regions have the largest area planted to sorghum (15.5, 14.6 and 14.2 per cent, respectively) followed by Mura (12 per cent), Tabora (10 per cent) and Lindi (8 per cent). The average sorghum yield for Tanzania is estimated to be approximately 1000 kg ha⁻¹, and too low to sustain an average farm family for 12 months (Brown, 2013). Popular varieties that had been released in Tanzania prior to the data collection for this study include *Pato* (released in 1995) and *Macia* (released in 1999). Other improved varieties released in Tanzania include *Tegemeo, Wahim, Hakika, Sila, Serena and Lulu*. These new releases have been widely disseminated and are being adopted by the farming population.

Despite its low productivity, the growing demand for sorghum in Tanzania and the wider East Africa community offers a great opportunity for small-scale farmers to benefit from sorghum production. This demand has increased dramatically following a resolution by the East Africa Breweries Limited to use sorghum to produce one of its beer brands. According to figures by the Tanzanian Ministry of Agriculture, Food Security and Cooperatives, the annual demand for sorghum in Tanzania in 2011/12 was 3,360,000 metric tons, while the supply was 1,084,000 metric tons. Against the background of this highly

---

**Figure 1.** Sorghum planted area in Tanzania and surveyed districts

**Legend**

- Surveyed Districts
- Districts
- Sorghum harvested area (ha)
  - <= 244.4
  - 244.4 - 487.8
  - 487.8 - 731.2
  - 731.2 - 974.6
  - > 974.6

**Source:** Based on HarvestChoice (2015) data and https://gadm.org/
dynamic market, both the demand and production of sorghum Tanzania are projected to increase substantially by the year 2050. The supply is projected to increase by over 300 per cent from about a million tons in 2015 to close to 5 million tons in 2050, while the demand for sorghum is expected to double from about 900 thousand tons to about two million tons by 2050, turning Tanzania into a net exporter of sorghum (Orr et al., 2016).

2. Methodology

2.1 Analytical framework

The decision whether to adopt improved sorghum can be modeled using the general framework of utility maximization (Uaiene et al., 2009; Hassen, 2015). The authors start from the assumption that farmers adopt a new technology only when the utility gained from using such a technology is significantly greater than the utility gained without using it. Even though it is not possible to observe utility directly, a farmer’s adoption decision is observed through which their utility is indirectly inferred. Following Hassen (2015), the authors let $U_{is}^n$ be the benefit level in the state of non-adoption (n) of improved sorghum varieties (s); $U_{is}^a$ the benefit level in the state of adoption (a). A farmer will transit from the state of non-adoption to the state of adoption of variety (s) if:

$$Y_{is}^a = \frac{U_{is}^a}{C_0} - \frac{U_{is}^n}{C_0} > 0$$

(1)

The farmer will not adopt if:

$$Y_{is}^a = \frac{U_{is}^a}{C_0} - \frac{U_{is}^n}{C_0} < 0$$

(2)

where $Y_{is}^a$ is the latent net benefit of adopting or not adopting an improved sorghum variety.

As expressed by Neill and Lee (2001), the initial adoption decision and the continued use of the technology once it has been adopted can be explained by two discrete sequential decisions. Stage 1 represents the decision of whether or not to adopt sorghum, while Stage 2 represents the decision whether to dis-adopt or continue cultivating sorghum if sorghum has been adopted. The dependent variables in both stages of the decision process are dichotomous.

Given the contingent nature of the decision framework, correct and efficient estimation of determinants of dis-adoption requires a joint estimation of the two decisions and taking into account sample selection as to report dis-adoption of an improved sorghum, it is necessary to adopt it in the first place.

The adoption and abandonment transitions can be expressed in two latent equations with two latent stochastic variables $y_{i1}^*$ and $y_{i2}^*$ which capture the propensity to make the first and second transition in the adoption status, respectively, with the first transition representing the transition from non-adoption to adoption and second representing the transition from adoption to abandonment. Thus, the latent adoption and dis-adoption decisions are determined by:

$$y_{i1}^* = x_{i1} \beta_1 + \mu = \begin{cases} 1 & \text{if } y_{i1}^* > 0 \\ 0 & \text{if } y_{i1}^* \leq 0 \end{cases}$$

(3)
\[
y_i^* = x_i \beta + \varepsilon = \begin{cases} 
1 & \text{if } y_i^* > 0, y_i^* > 0 \\
0 & \text{if } y_i^* > 0, y_i^* \leq 0 \\
\text{not observed if } y_i^* \leq 0 \text{ or } y_i^* \leq 0
\end{cases}
\] (4)

Outcome where the latent variables \(y_i^*)\) and \(y_i^*)\) represent the utility that the \(i\)th household receives from adopting improved sorghum and continuing the use, respectively. They depend on vectors of farmer observed characteristics \(x_i\) which represent farmer observed characteristics for adopting/non-adopting sorghum and farmer observed characteristics affecting dis-continuous cultivation of sorghum, respectively; \(\beta_1\) and \(\beta_2\) are vectors of coefficients to be estimated; \(\mu\) and \(\varepsilon\) are error terms.

The latent variables \(y_i^*)\) and \(y_i^*)\) are, by definition, unobservable but instead the authors observe two binary variables \(y\) indicating if individuals actually make each of the two transitions. The observable binary variables, \(y_i\) and \(y_i\) have the value of 1 when \(y_i^*) > 0\) and \(y_i^*) > 0\), respectively. Thus, the binary variables are defined as \(y_i = 1\) if a household adopts an improved sorghum variety and if \(y_i = 1\), then \(y_i\) could be 1 (indicating continuous adoption) or 0 (for abandonment). If \(y_i = 0\), then \(y_i\) is not observed or does not exist implying that the latent variable \(y_i^*)\) is only observed if \(y_i^*) > 0\) (Kim, 2017). In other words, it is only possible to observe \(y_i\) (continuation adoption decision) if a household adopted improved sorghum \(y_i^*) > 0\). An important observation for equation (2) which represents continued cultivation of improved sorghum is that a smaller number of households enters the equation. This can be called the censoring of the original sample (Kim, 2017; Sanou et al., 2017). Indeed, as expressed by Sanou et al. (2017), only a subset of original sample adopts the technology [equation (1)], continued use is observed only for those who adopt the technology [equation (2)].

It is assumed that the unobserved error vector \((\mu, \varepsilon)\) is distributed bivariate normal with zero mean and independently to the explanatory variables \(X_i\) and \(X_i\) where:

\[
\mu \sim N(0, 1) \sim N(0, 1) \text{corr}(\mu, \varepsilon) = \rho
\] (5)

The log-likelihood function of the model is given by the following equation:

\[
\ln L = \sum_i \left\{ y_1 y_2 \left( \ln \varphi_2(x_1 \beta_1, x_2 \beta_2, \rho) + y_1 (1 - y_2) \ln \varphi_2(x_1 \beta_1, x_2 \beta_2, -\rho) \right) + (1 - y_1) \ln \varphi_1(-x_1 \beta_1) \right\}
\] (6)

where \(i = 1, 2, \ldots, N\). As expressed by Sanou et al. (2017) in specification (4), \(\varphi_1\) is the univariate normal distribution, and \(\varphi_2\) is the bivariate normal distribution; \(y_1\) and \(y_2\) are binary variables taking unity if farmer \(i\) adopts improved sorghum and if farmer \(i\) continuously uses them, respectively, and 0 otherwise. And \(\rho\) is the coefficient of correlation.

Our estimated conditional probability derived from equations (1) and (2) is a bivariate Probit with sample selection model (Heckman, 1976). A bivariate probit model allows for a continuous structure of utility between the two decisions. It provides a correlation term \(\rho\) that represents how the unobserved characteristics affecting utility maximization, implicit in the first decision, are related to the second (Neill and Lee, 2001). If the null hypothesis that
\( \rho = 0 \) cannot be rejected, there is no correlation between the error terms of the two equations, and they may be estimated with separate probit specifications.

2.2 Data

The data for the study are based on a survey of 767 households from 57 villages across 8 of the major sorghum growing districts in mainland Tanzania and collected by ICRISAT in collaboration with Selian Crops Research Institute of Tanzania in 2011. The villages for the survey were drawn from the National Master Sample (NMS) developed by the National Bureau of Statistics (NBS) to serve as a national framework for conducting household-based surveys in Tanzania developed from the 2002 population and housing Census. A multistage sampling procedure was used in the selection of households for the study. The first stage involved the selection of major sorghum growing regions. The second stage involved the selection of major sorghum growing districts followed by the selection of villages and the households from each of the selected villages.

Four major sorghum growing regions (Dodonoma, Shinyanga, Singida and Tabora) were selected for the survey. The locations of the eight districts within these four regions where the study was conducted are highlighted in Figure 1.

The sampling process was proportional to the size with 5-8 villages selected per district leading to the total of 60 villages. In total, 15-30 households were randomly sampled per village based on population of the village, leading to the sampling of 800 households.

2.3 Model specification

The model specification involves assigning \( y_1 = 1 \) in equation (1) above for the first adoption decision and assigning \( y_2 = 1 \) for the continuous adoption. Non-adoption is represented by \( y_1 = 0 \) and abandonment of the technology by \( y_2 = 0 \). As expressed by Neill and Lee (2001), this specification implies that positive coefficients in both decisions are associated increasing the probability of growing improved sorghum varieties, while negative coefficients will be associated with a decreasing probability. The two separate equation specifications are estimated taking into account a number of variables such as farm size, market access, incidence of biotic stresses as well as other socio-economic variables. Table III depicts expected coefficient signs for the variables included in both equations.

2.3.1 Dependent variables. The dependent variables for the study relate to adoption and the subsequent dis-adoption. The analysis is based on two interrelated dependent variables. One reflects whether a farm household has ever cultivated at least one improved sorghum variety. The other dependent variable reflects dis-adoption patterns, where dis-adoption is defined as ever-growing an improved variety before 2011, but did not grow it in the year of survey in 2011 for whatever reason. The authors ran one pooled regression involving all improved varieties and four separate regressions for each of the improved varieties (serena, macia, tegemeo and pato).

2.3.2 Description of explanatory variables and hypotheses. The variables that are hypothesized to influence adoption and dis-adoption of improved sorghum varieties were selected based on a review of theoretical work and previous empirical adoptions studies (Feder et al., 1985; Diagne, 2006; Kassie et al., 2013). Below, a brief description of the variables and a priori expectation on their effect on adoption and dis-adoption is presented (Table I).

2.3.2.1 Household demographic and socioeconomic characteristics. Empirical studies (Adesina and Baidu-Forson, 1995; Uaïene et al., 2009) have shown that the age of a household’s head, which captures his or her farming experience could influence adoption decision, either positively or negatively. Adesina and Baidu-Forson (1995) finds that age
positively influenced the adoption of sorghum in Burkina Faso, while Polson and Spencer (1991) observe the contrary when they find that the younger farmers are more risk-taking and willing to uptake an improved technology. This makes it difficult to predict the impact of age on the continuity of the technology adoption. It is more difficult to predict the effect of gender on sorghum technology adoption and dis-adoption, although Schipmann et al. (2013) showed no gender impacts on sorghum adoption. The size of the household, is a proxy for the availability of labour. Generally, the production of improved sorghum varieties is relatively less labour intensive as Schipmann et al. (2013) report. Thus, the authors expect the coefficient to have a negative sign. The size of the land owned can have an impact of whether or not to adopt improved varieties. Generally, varieties that produce higher yields are likely to be attractive to those with small land holdings, leading to an expected negative sign for the coefficient for both the adoption and the abandonment equations. However, land is also a wealth proxy variable which can have a positive effect on the adoption of improved sorghum varieties (Feder et al., 1985).

The participation in off-farm self-employment can have unpredictable impacts on adoption and dis-adoption. Reasons for participation in off-farm employment include:

- self-insurance against risk;
- an ex-post coping strategy;
- inability to specialize due to incomplete input markets; and
- consumption diversification where there are incomplete output markets.
Thus, it is hard to predict the sign of the coefficient on both adoption and dis-adoption.

2.3.2.2 Exposure and social capital variables. Exposure and social capital variables are crucial drivers of adoption decisions of any technology. The knowledge of any friends and neighbors that grow improved sorghum is critical in adoption decisions as it exposes farmers to a new technology and increases the probability of adoption as reported in other studies (Diagne, 2006). However, a prediction on its impact on abandonment is not possible. As expressed by Schipmann et al. (2013), the information source for new sorghum cultivars plays an important role in adoption.

2.3.2.3 Community variables, biotic and abiotic factors. Market access was assessed using the distance to the main market which reflects transaction costs associated with buying inputs and taking produce to the market. Apart from affecting the access to the market, these distances can also affect the availability of new technologies, information and credit institutions (Kassie et al., 2013). The authors therefore expect the relationship between the distance to the market and adoption of improved sorghum varieties to be negative for both, the first adoption equation and the continued adoption equation as the incentive to produce sorghum is expected to be lower the further away from the market. Moreover, the authors also want to understand the effect of abiotic and biotic stresses such as drought, pest and diseases on the adoption as well as the sustainability of technology adoption. The occurrence of drought is likely to make sorghum production attractive and more so if improved varieties are drought tolerant or if they have short growth cycles favorable for the semi-arid areas, while the occurrence of pests and diseases and the lack of seed will have a negative effect on the adoption and encourages variety abandonment.

3. Results

3.1 Descriptive results

3.1.1 Types of sorghum varieties planted. Table II presents sorghum varieties grown in Tanzania and their rates of abandonment. The levels of adoption for different sorghum varieties vary extensively across farmers. Column 3 shows the numbers of farmers expressing that they ever grew the variety of sorghum. Local sorghum varieties are quite popular in Tanzania with all farmers reporting to have ever grown local sorghum varieties and 76 per cent reporting growing them in the year of the survey. Among improved varieties, Macia, Serena, Pato and Tegemeo were the most popular varieties, a finding consistent with Schipmann et al. (2013). Serena, Pato and Macia are widely preferred for their tolerance to striga (Striga hermonthica, Striga asiatica, and Striga forbesii), while Tegemeo is highly susceptible to striga. Column 5 depicts the rate at which farmers are abandoning each variety regardless of the time when the varieties were abandoned.

<table>
<thead>
<tr>
<th>Sorghum variety</th>
<th>Year of release</th>
<th>Ever planted (%) (n = 767)</th>
<th>Planted in 2011 (%) (n = 767)</th>
<th>(%) dis-adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local sorghum</td>
<td>–</td>
<td>100.0</td>
<td>75.9</td>
<td>24.1</td>
</tr>
<tr>
<td>Serena</td>
<td>1960</td>
<td>10.0</td>
<td>5.9</td>
<td>41.6</td>
</tr>
<tr>
<td>Pato</td>
<td>1977</td>
<td>14.6</td>
<td>8.2</td>
<td>43.8</td>
</tr>
<tr>
<td>Tegemeo</td>
<td>1978</td>
<td>11.6</td>
<td>4.8</td>
<td>58.4</td>
</tr>
<tr>
<td>Macia</td>
<td>1998</td>
<td>30.2</td>
<td>23.3</td>
<td>22.8</td>
</tr>
<tr>
<td>Wahi</td>
<td>2002</td>
<td>5.1</td>
<td>4.0</td>
<td>20.5</td>
</tr>
<tr>
<td>Hakika</td>
<td>2002</td>
<td>0.8</td>
<td>0.5</td>
<td>33.3</td>
</tr>
<tr>
<td>Sila</td>
<td>2008</td>
<td>0.5</td>
<td>0.3</td>
<td>50.0</td>
</tr>
</tbody>
</table>

Table II. Types of sorghum varieties planted and dis-adopted
Tegemeo, Pato and Serena varieties recorded the highest abandonment rates of 58.4, 43.8 and 41.6 per cent by the farmers that had ever grown the varieties, respectively. While Macia was the most widely cultivated variety, only 22.8 per cent of the sorghum farmers did not grow the variety during the year of the survey. The low dis-adoption rate of Macia relative to other improved varieties may suggest that the Macia has some preferable characteristics that encourage farmers to continue growing the variety, but it could as well be that the variety is relatively new compared to the others.

Moreover, older varieties may also be suffering from the lack of seed. It is likely that sorghum seed companies are focusing on new improved sorghum varieties than the older varieties, making it difficult for farmers to access improved seed for older varieties such as Serena, Tegemeo and Pato. As depicted in Figure 2, there is a correlation between the age of the variety and the rate of its abandonment with older varieties such as Serena (50 yrs), Pato (34 yrs) and Tegemeo (33 yrs) registering higher dis-adoption rates of 42, 44 and 58 per cent, respectively.

3.1.2 Transitions in variety cultivation. As expressed by Westengen and Brysting (2014), switching to other varieties within the farming communities is an important adaptation strategy within a diverse portfolio of livelihood responses to multiple stresses. Table III depicts results of the adoption dynamics among sorghum farmers. Most farmers that had abandoned Serena, actually did not grow any sorghum variety (65.7 per cent), while a few (21.9 per cent) switched to the cultivation of mostly local varieties. Consistent with dis-adopters of Serena, most farmers that dis-adopted Macia (58.5 per cent) also did not grow any sorghum variety while 32.1 per cent of them switched to local varieties. A significant proportion of previous growers of Tegemeo and Pato also either quit sorghum production or

![Figure 2. Variety age versus rate of disadoption](image-url)
switched to the cultivation of local sorghum varieties. Variety switching within improved varieties is largely limited to Macia, with 17.3 per cent and 28.6 per cent of the previous growers of Tegemeo and Pato, respectively, switching to Macia. The findings largely suggest that most sorghum farmers are moving out of sorghum cultivation to other enterprises.

3.1.3 Reasons for dis-adopting of sorghum varieties. The qualitative information on what motivates the dis-adopt of certain varieties of sorghum is depicted in Table IV. This information is quite useful, as it allows for a much richer analysis of farmer’s decision-making and underlying rationale with regards to technologies (Grabowski et al., 2016). It allows for a greater contextualization of the econometric analysis that follows later. Overall, the lack of seed is featured highly as the main reason for abandoning sorghum cultivation, but the problem is more pronounced among those who had planted Pato in the past. This underscores the need to strengthen sorghum seed systems as a way of sustaining sorghum production. Local varieties were abandoned due to their susceptibility to drought and low yields. Attacks by diseases and pests on Macia and birds on Tegemeo and the lack of market for Serena sorghum varieties were among the most frequently reported reasons for abandoning the cultivation of some sorghum varieties.

3.1.4 Socioeconomic and demographic characteristics by adoption status. Descriptive statistics for selected variables for the sampled households disaggregated by the adoption status of improved sorghum varieties are presented in Table V. About three in four farmers were male, while the average age was 44 years among the sampled households. An average household was comprised of about six members with an average land holding size of four hectares. About 70 per cent of the respondents expressed knowledge of friends/neighbors that grew improved sorghum varieties. A significantly higher proportion of adopters (92 per cent) knew of some farmer/friend growing improved sorghum varieties compared to only 48 per cent for the non-adopters. The average distance to the main markets was 22 kilometers, and adopters were closer to the market (23.9 km) than those that abandoned (30 km) the cultivation of improved varieties. In terms of sources of extension information, the majority (59 per cent) expressed accessing information through other farmers, while 35 per cent of the farmers accessed information through government extension workers. A significantly higher proportion of non-adopters (77 per cent) reported access extension information through other farmers as compared to adopters (45 per cent) a finding that suggests that over-reliance on informal extension systems may be ineffective in the diffusion of appropriate and improved technologies among farmers. On the contrary, only 17 per cent of non-adopters accessed information through a conventional government extension system compared to 48 per cent for the adopters and 57 per cent for the abandoners.

<table>
<thead>
<tr>
<th>Reason for dis-adopting</th>
<th>Local ((n = 165))</th>
<th>Serena ((n = 32))</th>
<th>Tegemeo ((n = 52))</th>
<th>Pato ((n = 49))</th>
<th>Macia ((n = 53))</th>
<th>Total ((n = 351))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of seed</td>
<td>10.9</td>
<td>19.3</td>
<td>34.5</td>
<td>57.2</td>
<td>30.2</td>
<td>25.3</td>
</tr>
<tr>
<td>Requires more rainfall</td>
<td>47.3</td>
<td>5.3</td>
<td>6.9</td>
<td>1.8</td>
<td>1.9</td>
<td>21.7</td>
</tr>
<tr>
<td>Diseases and pests</td>
<td>10.3</td>
<td>14.0</td>
<td>13.8</td>
<td>10.7</td>
<td>34.0</td>
<td>14.5</td>
</tr>
<tr>
<td>Birds attack</td>
<td>2.4</td>
<td>15.8</td>
<td>27.6</td>
<td>17.9</td>
<td>20.8</td>
<td>16.2</td>
</tr>
<tr>
<td>Lack of market and poor prices</td>
<td>12.1</td>
<td>33.5</td>
<td>12.1</td>
<td>3.6</td>
<td>7.5</td>
<td>9.4</td>
</tr>
<tr>
<td>Low yielding variety</td>
<td>11.5</td>
<td>1.8</td>
<td>0.0</td>
<td>0.0</td>
<td>5.7</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Table IV. Reasons for dis-adopting the sorghum production (%)
3.2 Econometric results

3.2.1 Determinants of adoption of all improved varieties. The determinants of sustained adoption for all improved sorghum varieties are presented in Table VI based on the maximum likelihood estimates from a Heckman bivariate probit. The estimation was done in three models: Model 1 has no extension services and membership in social groupings variables, Model 2 includes extension services, while Model 3 includes membership in social groupings. The inclusion of the extension services in Model 2 slightly alters some results, but does not change the coefficients much compared to Model 1, suggesting that the district dummies sufficiently control for the observable factors. The model chi-square, which measures the goodness of fit of the model is significant at 1 per cent level, indicating a good fit. The correlation term, $\rho$ is not significant suggesting that the unobservable attributes that affect the decision to adopt improved sorghum varieties do not affect the decision to continue growing these varieties. Although the results suggest that the residuals of the two probit equations are not significantly correlated, the maximum likelihood results are maintained as simultaneous estimation by maximum likelihood is more efficient than separate estimation of each of the probit equations. The age of the head of household does not significantly influence the first adoption of improved sorghum varieties, but the relationship between age and the first adoption status is nonlinear as the square of age has a positive and significant effect on the first adoption suggesting that as farmers grow beyond some tipping point of age.

The effect of extension services was assessed by including different sources of extension information in the regression as dummy variables and using government extension as a reference point. Highlighting the importance of government extension systems, farmers that relied more on members of farmer club and fellow farmers in accessing agricultural information were less likely to adopt improved sorghum compared to farmers that accessed most of the information through the government extension system. The coefficient for

<table>
<thead>
<tr>
<th></th>
<th>Adopters $(n = 289)$</th>
<th>Abandoners $(n = 119)$</th>
<th>Non-adopters $(n = 359)$</th>
<th>Total $(n = 767)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender of household head (1 = male, 0 = female)</td>
<td>0.74</td>
<td>0.74</td>
<td>0.77</td>
<td>0.76</td>
</tr>
<tr>
<td>Age of the household member (yrs)</td>
<td>43.15</td>
<td>45.22</td>
<td>45.18</td>
<td>44.42</td>
</tr>
<tr>
<td>Years of education (yrs)</td>
<td>2.85</td>
<td>2.88</td>
<td>2.82</td>
<td>2.84</td>
</tr>
<tr>
<td>Household size</td>
<td>5.92</td>
<td>5.89</td>
<td>6.03</td>
<td>5.97</td>
</tr>
<tr>
<td>Distance to the main market (km)</td>
<td>23.9</td>
<td>30.0</td>
<td>18.1</td>
<td>22.1</td>
</tr>
<tr>
<td>Land holding size (ha)</td>
<td>4.87</td>
<td>3.43</td>
<td>3.95</td>
<td>4.21</td>
</tr>
<tr>
<td>Livestock units (LU)</td>
<td>6.4604</td>
<td>8.1718</td>
<td>6.8375</td>
<td>6.903</td>
</tr>
<tr>
<td>Whether knows friends growing sorghum (yes = 1, 0 = otherwise)</td>
<td>0.92</td>
<td>0.85</td>
<td>0.48</td>
<td>0.71</td>
</tr>
<tr>
<td>Number of friends known planting sorghum</td>
<td>15.58</td>
<td>17.36</td>
<td>5.60</td>
<td>11.19</td>
</tr>
<tr>
<td>Years of experience in sorghum farming (yrs)</td>
<td>13.88</td>
<td>13.46</td>
<td>13.86</td>
<td>13.8</td>
</tr>
<tr>
<td>Sources of information</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government (yes = 1, 0 = otherwise)</td>
<td>0.48</td>
<td>0.57</td>
<td>0.17</td>
<td>0.35</td>
</tr>
<tr>
<td>Farmer club (yes = 1, 0 = otherwise)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>NGO (yes = 1, 0 = otherwise)</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Research Centre (yes = 1, 0 = otherwise)</td>
<td>0.02</td>
<td>0.03</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Seed/grain dealer (yes = 1, 0 = otherwise)</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Another farmer (yes = 1, 0 = otherwise)</td>
<td>0.45</td>
<td>0.36</td>
<td>0.77</td>
<td>0.59</td>
</tr>
<tr>
<td>Participation in off farm employment (yes = 1, 0 = otherwise)</td>
<td>0.22</td>
<td>0.26</td>
<td>0.26</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table V. Means statistics for adopters, abandoners and no adopters
### Table VI.
Bivariate Heckman probit estimates of the adoption and abandonment of improved sorghum varieties

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Model (1)</th>
<th>Model (2)</th>
<th>Model (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adoption</td>
<td>Cont.use</td>
<td>Adoption</td>
</tr>
<tr>
<td>Gender (1 = male, 0 = female)</td>
<td>-0.12 (0.13)</td>
<td>0.06 (0.18)</td>
<td>-0.04 (0.14)</td>
</tr>
<tr>
<td>Age of household head yrs</td>
<td>-0.38 (0.38)</td>
<td>-18.69 (11.98)</td>
<td>-0.62 (0.38)</td>
</tr>
<tr>
<td>The square of age</td>
<td>0.01* (0.00)</td>
<td>2.45 (1.57)</td>
<td>0.01* (0.00)</td>
</tr>
<tr>
<td>Education (0 = low, 1 = high)</td>
<td>0.19 (0.17)</td>
<td>-0.02 (0.25)</td>
<td>0.13 (0.17)</td>
</tr>
<tr>
<td>Household size</td>
<td>0.04 (0.15)</td>
<td>0.12 (0.25)</td>
<td>0.05 (0.16)</td>
</tr>
<tr>
<td>Distance to market (km)</td>
<td>0.01 (0.03)</td>
<td>-0.10*** (0.04)</td>
<td>0.02 (0.03)</td>
</tr>
<tr>
<td>Land holding size (ha)</td>
<td>0.02 (0.04)</td>
<td>0.08 (0.07)</td>
<td>0.02 (0.04)</td>
</tr>
<tr>
<td>Total livestock units</td>
<td>0.05** (0.03)</td>
<td>-0.03 (0.04)</td>
<td>0.03 (0.03)</td>
</tr>
<tr>
<td>Quality of house roof (1 = iron sheet, 0 = otherwise)</td>
<td>-0.45*** (0.15)</td>
<td>0.15 (0.19)</td>
<td>-0.42*** (0.15)</td>
</tr>
<tr>
<td>Quality of wall (1 = bricks, 0 otherwise)</td>
<td>0.04 (0.19)</td>
<td>0.28 (0.30)</td>
<td>-0.03 (0.19)</td>
</tr>
<tr>
<td>Neighbors growing improved sorghum</td>
<td>0.21*** (0.02)</td>
<td>-0.07 (0.13)</td>
<td>0.19*** (0.02)</td>
</tr>
<tr>
<td>Participation in off farm employment (1 = yes, 0 = otherwise)</td>
<td>0.09 (0.18)</td>
<td>-0.10 (0.26)</td>
<td>0.04 (0.15)</td>
</tr>
<tr>
<td>Seed constraints (1 = yes, 0 = otherwise)</td>
<td>0.29 (0.23)</td>
<td>-2.11*** (0.43)</td>
<td>0.22 (0.25)</td>
</tr>
<tr>
<td>Disease and pests (1 = yes, 0 = otherwise)</td>
<td>-0.07 (0.27)</td>
<td>-1.79*** (0.4)</td>
<td>-0.30 (0.27)</td>
</tr>
<tr>
<td>Birds constraint (1 = yes, 0 = otherwise)</td>
<td>0.95** (0.45)</td>
<td>-6.67*** (0.99)</td>
<td>0.78 (0.48)</td>
</tr>
</tbody>
</table>

**Main sources of information (base-government extension agents)**

<table>
<thead>
<tr>
<th>Source</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer club members</td>
<td>-1.02*** (0.33)</td>
<td>0.07 (0.47)</td>
<td>-0.99*** (0.32)</td>
<td>0.04 (0.39)</td>
</tr>
<tr>
<td>Research Centre</td>
<td>0.13 (0.42)</td>
<td>0.33 (0.42)</td>
<td>0.08 (0.37)</td>
<td>0.03 (0.51)</td>
</tr>
<tr>
<td>Seed stockiest</td>
<td>0.11 (0.49)</td>
<td>0.51 (0.75)</td>
<td>0.16 (0.51)</td>
<td>0.52 (0.73)</td>
</tr>
<tr>
<td>Another farmer</td>
<td>-0.72*** (0.13)</td>
<td>-0.12 (0.23)</td>
<td>-0.74*** (0.13)</td>
<td>0.35 (0.22)</td>
</tr>
<tr>
<td>Membership in farmers association (1 = member, 0 = otherwise)</td>
<td>0.41*** (0.18)</td>
<td>0.06 (0.23)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**District dummies**

| Constant | 0.46 (1.56) | 39.2* (20.7) | 0.18 (1.14) | 30.6 (21.4) | 1.26 (1.14) | 38.81*** (14.14) |
| ρ | -0.70 (0.52) | 0.46 (0.57) | 0.54 (0.39) |
| Observations | 766 | 766 | 766 |
| Censored obs | 359 | 359 | 359 |
| Wald ch² | 198.5*** | 394.5*** | 284.6*** |

**Notes:** *, **, *** represent significance at 10, 5 and 1%, respectively; Figures in parentheses are standard errors.
research organization as sources of information was positive but not significant suggesting that accessing information through research organizations did not significantly influence the adoption of improved sorghum varieties. Indeed, the research organizations’ lack of positive influence on farmer’s adoption could indicate a more important underlying problem of failure to communicate effectively with farmers which should be carefully looked into from the research organizations’ perspective.

Underscoring the role of access to appropriate social networks, the coefficient for the number of neighbours known by the farmer that grow improved sorghum varieties was positive and significant at 1 per cent level suggesting that farmers with proximity to neighbours growing improved sorghum varieties increased the propensity for adoption. Furthermore, consistent with prior expectation and the observed influence of others farmers as information sources, membership in a farmer’s association significantly and positively affects the household’s adoption decision. The positive relationship could be attributed to positive peer effects in sorghum adoption. However, as expressed by Orr et al. (2016) sorghum has a reputation as a “poor man’s crop” for which demand declines as income rises as such the results suggest that well-off farmers are less likely to grow improved sorghum. The negative effect of the ownership of residential houses that are roofed with iron sheets as opposed to a grass thatch on the adoption of improved sorghum varieties is consistent with this notion of sorghum being mainly grown by the poorer households.

3.2.2 Determinants of continued use of improved sorghum varieties. The conditional decision to abandon or sustain sorghum cultivation shows that the age of the farmers is a significant determinant of whether a farmer sustains the cultivation of improved sorghum over a longer period. The age of a farmer was negatively associated with continued sorghum cultivation perhaps reflecting an increase in the viability of non-sorghum enterprises over time. However, signifying the non-linear relationship between age and continued cultivation, the squared of age was positive indicating an increasing negative effect on continued adoption. The coefficient for the distance to the input and output market was negative and significant (at 1 per cent level) suggesting that households far from the market were more likely to abandon the cultivation of improved sorghum varieties than those close to markets. The results are consistent with the well-established theory around the positive role of markets in propelling the sustainability of food systems. Through access to markets, farmers may access inputs while also finding the opportunity for marketing their products. The importance of market access could also be based on the possibility that modern varieties may not always be consistent with the households’ consumption demands but are tailored to other markets like the brewing industry. In fact, most of the sorghum varieties released in Tanzania are recommended for beer processing. With regards to this, Orr et al. (2016) report that in Tanzania, the use of sorghum for food processing exceeds the use of sorghum for food. Most of the abiotic and biotic constraints were found to be responsible for the abandonment of sorghum cultivation. The bird problem is endemic to Tanzanian sorghum farmers who feel researchers are not doing enough to address the problem. Consistent with this notion Laswai et al. (2008) report that the bird problem has been neglected. Breeders, who have succeeded in improving the yield of compact-headed sorghums that are more easily attacked by birds do not seem to see the damage caused as a problem needing immediate attention. Accordingly, some new varieties such as Tegemeo and Serena remain highly susceptible to birds with farmers growing Serena sometimes reporting crop losses of up to 100 per cent as a result of bird damage (Monyo et al., 2004). Sorghum varieties with loose heads, like the local varieties, could offer a solution to the bird problem and make these attractive to many farmers.

3.2.3 Determinants of abandonment for specific improved sorghum varieties. Table VII presents results of dis-adoption of the four most widely cultivated improved sorghum
Table VII. Bivariate Heckman probit estimates of adoption and abandonment of specific improved sorghum varieties

<table>
<thead>
<tr>
<th>Variables</th>
<th>Serena</th>
<th>Tegemeo</th>
<th>Pato</th>
<th>Macia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continued adoption</td>
<td>First adoption</td>
<td>Continued adoption</td>
<td>First adoption</td>
</tr>
<tr>
<td>Gender</td>
<td>-0.119, 0.307</td>
<td>0.277*, 0.164</td>
<td>-0.677, 0.474</td>
<td>0.125, 0.154</td>
</tr>
<tr>
<td>Age</td>
<td>8.177, 9.033</td>
<td>-0.526, 0.413</td>
<td>-2.237, 16.951</td>
<td>-0.062, 0.481</td>
</tr>
<tr>
<td>Age squared</td>
<td>-1.651, 1.193</td>
<td>0.000, 0.000</td>
<td>2.860, 2.248</td>
<td>-0.000, 0.000</td>
</tr>
<tr>
<td>Education</td>
<td>-0.196, 0.246</td>
<td>0.151, 0.208</td>
<td>-0.234, 0.570</td>
<td>0.188, 0.224</td>
</tr>
<tr>
<td>Household size</td>
<td>-0.076, 0.278</td>
<td>-0.40**, 0.175</td>
<td>-0.188, 0.547</td>
<td>0.040, 0.151</td>
</tr>
<tr>
<td>Distance to market</td>
<td>0.653, 0.031</td>
<td>0.001, 0.018</td>
<td>-0.198*, 0.107</td>
<td>0.076**, 0.034</td>
</tr>
<tr>
<td>Land size</td>
<td>0.062, 0.061</td>
<td>-0.021, 0.032</td>
<td>0.288**, 0.119</td>
<td>-0.016, 0.036</td>
</tr>
<tr>
<td>Livestock units</td>
<td>0.039, 0.040</td>
<td>0.067*, 0.035</td>
<td>0.003, 0.091</td>
<td>0.014, 0.030</td>
</tr>
<tr>
<td>Neighbors growing improved sorghum</td>
<td>0.04**, 0.020</td>
<td>0.122***, 0.025</td>
<td>0.158***, 0.024</td>
<td>0.168***, 0.027</td>
</tr>
<tr>
<td>Off farm employment</td>
<td>0.004, 0.247</td>
<td>-0.198, 0.174</td>
<td>-0.412, 0.504</td>
<td>0.415***, 0.154</td>
</tr>
<tr>
<td>Farmer club members</td>
<td>0.200, 0.373</td>
<td>0.450, 0.597</td>
<td>-0.489, 0.520</td>
<td>-0.645, 0.489</td>
</tr>
</tbody>
</table>

Main sources of information (base-government extension agents)

<table>
<thead>
<tr>
<th>Sources</th>
<th>Coeff.</th>
<th>Se</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-governmental</td>
<td>0.342, 0.443</td>
<td>0.705, 0.619</td>
</tr>
<tr>
<td>Research organizations</td>
<td>-0.9***, 0.258</td>
<td>0.284, 0.453</td>
</tr>
<tr>
<td>Seed/ grain stockiest</td>
<td>0.782**, 0.367</td>
<td>-1.202**, 0.567</td>
</tr>
<tr>
<td>Another farmer</td>
<td>-0.5***, 0.139</td>
<td>-0.313**, 0.159</td>
</tr>
<tr>
<td>Bird constraints</td>
<td>-6.4**, 0.258</td>
<td>-1.39**, 0.54</td>
</tr>
<tr>
<td>Pest and disease constraint</td>
<td>-0.835, 0.742</td>
<td>-0.662***, 0.227</td>
</tr>
<tr>
<td>Drought constraint</td>
<td></td>
<td>-0.552, 0.583</td>
</tr>
<tr>
<td>Constant</td>
<td>-17.161, 16.862</td>
<td>4.643, 31.472</td>
</tr>
<tr>
<td>Athrho</td>
<td>12.404***, 0.095</td>
<td>-0.247, 1.039</td>
</tr>
<tr>
<td>Observations</td>
<td>766</td>
<td>766</td>
</tr>
<tr>
<td>N_censored</td>
<td>689</td>
<td>677</td>
</tr>
</tbody>
</table>

**N** ***p < 0.01, **p < 0.05, *p < 0.1
varieties: Macia, Pato, Serena and Tegemeo. The results on variety abandonment show that the age of the farmer has a negative influence on the continued adoption of Macia, suggesting that conditional on first adoption, younger farmers abandon the cultivation of Macia. The abandonment of Macia could be attributed to the fact that it is more susceptible to kernel smut than either Tegemeo or Pato (Monyo et al., 2004). Age does not significantly influence the continued adoption of Serena, Tegemeo and Pato. The coefficient for the size of the household in the Macia regression was positive and significant suggesting that larger households were more likely to continue cultivating Macia over a long period. The distance to the market was negative was only significant for two varieties (Tegemeo and Macia) which suggests that households far away from the market tend to abandon the cultivation of these two varieties if they have adopted them before.

4. Conclusions
This paper analyzes the factors affecting the adoption and abandonment of sorghum varieties in Tanzania using the bivariate selection model. The results indicate that sustained cultivation of improved sorghum varieties highly depends on the extent of access to output and input markets. Through access to markets, farmers may access inputs such as seed, while also finding the opportunity for marketing their products. The lack of access to seed was reported as a major reason for abandoning sorghum, and this can be a big constraint where farmers are far from seed markets. The significance of market access in sustaining the cultivation of all sorghum varieties underscores the need to address market failure among farmers. Moreover, young farmers are less likely to abandon the cultivation of improved varieties which clearly indicates an avenue for extension to specifically focus on this group and makes it likely that Sorghum will play a more significant role in the future. The occurrence of biotic stresses such as diseases and birds, however, significantly influences farmers to abandon the cultivation of improved sorghum varieties. The bird problem mainly encourages the abandonment of the Tegemeo variety but clearly highlights the need for this issue to be taken serious in future breeding efforts.

These findings suggest that there is hope for improving and sustaining the adoption of sorghum varieties in Tanzania once extension services are strengthened and breeding programs also focus on farmers needs and not purely on industry demands. Accordingly, for some varieties such as Tegemeo, minimizing bird and disease related losses should be considered a priority if abandonment by farmers is to be reduced and sorghum production to be sustained.

Note
1. See also the heckprob command in the Stata 10.0 reference manual (pp. 570-572).

References


**Further reading**


**Corresponding author**

Franklin Simtowe can be contacted at: f.simtowe@cgiar.org

For instructions on how to order reprints of this article, please visit our website: [www.emeraldgrouppublishing.com/licensing/reprints.htm](http://www.emeraldgrouppublishing.com/licensing/reprints.htm)

Or contact us for further details: permissions@emeraldinsight.com
Crop switching as an adaptation strategy to climate change: the case of Semien Shewa Zone of Ethiopia

Yibekal Abebe Tessema, Jonas Joerin and Anthony Patt

Climate Policy Group, Department of Environmental Systems Science, ETH Zurich, Zurich, Switzerland

Abstract

Purpose – The geographical range of agricultural crops is shifting because of climate change. Reducing the potential negative impact of this shift requires efficient crop switching at farm level. Yet there are scant studies that examine how crop switching is currently taking place and what factors facilitate the process. Even these few existing studies often based their analysis on inadequately established causal link between climate change and switching decisions. This study aims to identify the specific switching decisions that are primarily motivated by climate change, and their determinants.

Design/methodology/approach – The study used a household survey on 190 households in Semien Shewa Zone in Ethiopia. Subjective rating of farmers was used to identify the relative importance of climate change in motivating the different types of switching decisions. A logit model is used to identify determinants of crop switching decisions primarily motivated by climate change.

Findings – Farmers in the study area are currently abandoning certain crops as a response to climate change. The adoption of new crops is, however, mainly attributed to price changes. Most farmers who abandoned at least one crop adopted mung bean mainly due to its price advantages. As expected, crop switching as an adaptation strategy is more prevalent particularly in drier and hotter agroecologies. The logit model showed that crop switching is strongly correlated with land size and agroecology.

Originality/value – This paper provides an in-depth examination of crop switching as an adaptation strategy to climate change. Crop switching is an adaptation strategy that is expected to substantially reduce the damage from climate change in agriculture. The findings are particularly relevant for adaptation planning in the context of smallholder agriculture.

Keywords Crop switching, Climate change, Adaptation, Determinant, Logit, Ethiopia

Paper type Research paper

1. Introduction

Major shift is projected in the suitable climate space of many crops across the globe due to climate change (Seo and Mendelsohn, 2008; Wang et al., 2010; Rippke et al., 2016). This phenomenon is similar to the range-shift of plant species pole wards, or upwards for elevation-induced climate zones. Many species have recently shifted their ranges toward higher elevations and latitudes at a median rate of 11.0 m and 16.9 km per decade, respectively (Chen et al., 2011). Similarly, the geographical range of agricultural crops is
expected to shift. In sub-Saharan Africa, the area suitable for maize and beans, two of the nine major crops in the region, is predicted to shrink by about 30 and 60 per cent, respectively, by the end of the twenty-first century (Rippke et al., 2016). These shifts entail transformational adaptations such as substituting maize with more drought-resistant crops such as sorghum and millet (Rippke et al., 2016).

To avoid or reduce the potential loss in profit due to shifts in suitable climate spaces, farmers need to make appropriate adjustments particularly crop switching. Global modeling studies suggest that two-thirds of the potential damage from climate change in the agricultural sector can be avoided by effective crop switching (Costinot et al., 2016). We define crop switching here to consist of two types of adjustments:

1. starting the adoption of a new crop for the first time; and
2. abandonment of existing crops.

Therefore, the term switching is better understood at plot level rather than farm level, i.e. adopting a new crop does not necessarily mean abandoning existing ones, and vice versa.

Studies in the past have examined the process of crop switching as an adaptation response and the factors that facilitate it. Most of these studies focused on revealing whether farmers are adapting by switching crops and what type of socio-economic and environmental factors influence the process (Maddison, 2007; Deressa et al., 2011; Gbetibouo, 2009; Bryan et al., 2013). These studies often consider crop switching just as one type of adaptation response without attempting to disentangle the specific types of switching decisions that are primarily motivated by climate change. This can be considered a key gap in the literature because certain types of switching decisions could be caused by non-climatic drivers such as price (Seo and Mendelsohn, 2008). Moreover, earlier studies do not give appropriate focus to non-climatic variables (Below et al., 2012; Fosu-Mensah et al., 2010; Gbetibouo et al., 2010). Crop switching, however, takes place in the context of different drivers such as markets dynamics, pest occurrence and land degradation. The consideration of such drivers is, therefore, vital to understand the relative importance of climate change in switching crops.

Few studies partially addressed the common methodological gaps in the literature. Alauddin and Sarker (2014) identified the determinants of a specific category of crop switching decision (adopting water-saving non-rice and horticultural crops) in a study area in Bangladesh. This is a major improvement from previous studies as it singles out narrowly defined types of switching decisions as adaptation strategies to climate change. The study, however, did not adequately clarify the basis for identifying the specific strategy as an adaptation response among others. Mertz et al. (2009) identified climate-induced crop adoptions in their study area in Senegal. An important contribution of the study is the fact that it categorizes adoption decisions at the level of individual crops, i.e. as adoption of millet, maize, etc. Unfortunately, the study relied on a small sample size and did not analyze the determinants of the short-listed crop switching decisions strongly induced by climate change.

The study builds on the works of Alauddin and Sarker (2014), and Mertz et al. (2009) to identify the specific types of crop switching decisions induced by climate change and their determinants. We first examine crop switching decisions specific to the level of individual crops with the aim of identifying the determinants of the specific crop switching decisions primarily motivated by climate change. The examination of crop switching in detail at the level of individual crops enables validating the results based on predictions from studies on crop distribution modeling and ecological change. This is a key addition to the literature on
farm-level adaptations in general where the link between climate change and farm adjustments is still unclear. The identification of the socio-economic and environmental determinants of crop switching is also vital to suggest interventions that could keep adjustment costs as minimal as possible.

2. Method

2.1 Study area

The study area, Semien Shewa Zone, is one of the administrative zones of Amhara Regional State of Ethiopia. It is located in the central highlands of the country; covers 15,936 km² area of land; and hosts about 1.8 million people (CSA, 2007). Ankober Woreda (district), which is one of the 24 districts in the administrative zone, was purposively selected. Ankober District was selected as it encompasses the typical crop production systems and agroecological zones (AEZs) in Semien Shewa Zone (CSA, 2013; Ege, 2005; Hurni, 1998). The district is found on an escarpment that stretches across four common AEZs, according to the traditional climate typology in the country: Kolla (lowland, altitude 500-1,500 m a.s.l.), Weynadega (middle land, 1,500-2,300 m a.s.l.), Dega (highland, 2,300-3,200 m a.s.l.) and Wurch (frosty zone, above 3,200 m a.s.l.) (Hurni, 1998). Kolla is characterized by drier and hotter climate with annual rainfall often below 1,400 mm, where some places may receive annual rainfall below 900 mm. Weynadega is relatively cooler and wetter than Kolla with annual rainfall from below 900 mm up to over 1,400 mm. Dega and Wurch are wetter and colder than the remaining zones often with annual rainfall over 900 mm reaching to over 1,400 mm. Wurch is, however, a much colder yet relatively rare agro-ecology with higher frequency of frost. Three Kebeles (Laygorebela, Alyuamba Zuria and Hagereselam), the lowest administrative unit, were selected from the 18 Kebeles in the district, making sure that all the four AEZs were included (Figure 1). There are two growing seasons in the study area:

1. Meher (depends on rainy season from June to September); and
2. Belg (rainy season from March to April) (Tanto Hadado et al., 2009).

Meher is the main growing season in the country (Tanto Hadado et al., 2009).

2.2 Sampling and data collection

A total sample size of 190 households was proportionally allocated among the four AEZs based on their coverage in the study area, Semien Shewa Zone. For the Wurch, however, which is a rare AEZ in the study area (Hurni, 1998; Ege, 2005), a sample size of 30 is allotted based on the central limit theorem. Kolla and Dega each were allocated a sample size of 40, while Weynadega took 80. Systematic random sampling was used to sample households from the selected three Kebeles. For this purpose, records of households from Kebele administrative offices were used. The study also made use of data collected in an earlier survey (in 2014) on the same households.

The rural household survey was conducted in January and February of 2016, and the data collected are for the immediately preceding growing seasons. To collect the data, a semi-structured interview schedule was used. The interview schedule was translated to Amharic, the common language in the study area, and was administered by nine enumerators. The first key area of enquiry was the types of crops permanently adopted or abandoned by farmers over the past 20 years. For each of these crop switching decisions, respondents were asked to identify the first and second most important drivers from a list of six potential drivers: climate change, pest and disease, price change, soil erosion and changes in intra household characteristics. The interview schedule clearly defined climate
change for respondents to differentiate it from short-term weather variability. The non-climatic drivers were selected based on their potential importance in Ethiopia (Eshte et al., 2015; PPSE, 2008; Shimeles and Delelegn, 2013; World Bank, 2007). Respondents were also given the option to mention other drivers in case the list is not exhaustive enough for them.

2.3 Data analysis

Descriptive statistical methods of frequency and bar graphs are used to describe the crop switching process and its relation to climate change. A binary regression model (logit) is applied to analyze the relation between farmers’ crop switching decision, those specifically linked to climate change, and the socio-economic and environmental context of farmers.

The logit model is defined below, where the log of the odds ratio for positive outcome of the dependent variable is represented as the function of the explanatory variables (Gujarati, 2004).

\[ L - \ln \left( \frac{P}{1 - P} \right) = \beta_0 + \beta_1 X_1 + \ldots + \beta_{10} X_{10} \]

Here, \( P/(1 - P) \) is the odds ratio for making an adaptive crop switching decision, where \( P \) stands for the probability of a positive outcome for the dependent variable, i.e. making an adaptive switching decision, whereas \( (1 - P) \) is the probability of not making the adaptive decision.
switching decision, $L$ stands for the logs of the odds ratio for a positive outcome of the dependent variable and $\beta_0$ is the constant term, while $\beta_1$ to $\beta_{10}$ are coefficients of the explanatory variables ($X_1 - X_{10}$) described in Table I. $L$ is estimated for given $X$ values.

For ease of interpretation, the marginal effect of $L_i$ is calculated as follows:

$$\text{Marginal effect} = \frac{\partial P}{\partial X}$$

The logit model is evaluated using Likelihood ratio test, Wald statistic, classification test, area under ROC curve (AUC) and variable inflation factor (VIF).

### 2.4 Empirical specification of explanatory variables

The explanatory variables for the logit model were selected based on empirical evidence on their importance in influencing farm adaptation responses in particular, and farm decision-making in general. The hypothesized relationships of the explanatory variables with crop switching along with their descriptive statistics are given in Table I.

The age of a farmer is hypothesized to be positively associated with crop switching because older farmers are more experienced and have a better chance of perceiving and adapting to climate change (Maddison, 2007). As switching crops is expected to occur primarily through locally available inputs, it is expected that the role of farm experience is pronounced. Larger land and family sizes represent more land and labor resources at the disposal of a farmer; therefore, they are expected to relax the resource constraints thereby facilitating any adjustment (Alauddin and Sarker, 2014; Yong, 2014; Shikuku et al., 2017; Croppenstedt et al., 2003) and hence positively influence switching crops. Particularly, larger land size allows farm experimentation, which may particularly accelerate crop switching. Farmers living close to markets are expected to be in advantage in accessing information (Maddison, 2007), while enjoying a relatively wider switching option with better prospect for profitability (Foster and Rosenzweig, 2010). Therefore, it is hypothesized that distance from market is inversely related to

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>Description</th>
<th>Hypothesized signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of the household head in years</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Land owned in ha</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Family size</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Walking distance from market in hours</td>
<td>Continuous</td>
<td>–</td>
</tr>
<tr>
<td>Level of education</td>
<td>Dummy, 0 if illiterate and 1 otherwise</td>
<td>+</td>
</tr>
<tr>
<td>Access to extension services</td>
<td>Dummy, 0 if without access, and 1 otherwise</td>
<td>+</td>
</tr>
<tr>
<td>Access to credit</td>
<td>Dummy, 0 if without access, and 1 otherwise</td>
<td>+</td>
</tr>
<tr>
<td>Access to irrigation</td>
<td>Dummy, 0 if without access, and 1 otherwise</td>
<td>+</td>
</tr>
<tr>
<td>Number of relatives (an estimated number of blood relatives in the village)</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>AEZs</td>
<td>Ordinal, 1 if Kolla (lowland), 2 if Weynadega (middle land), 3 Dega (highland), and 4 Wurch (Frosty)</td>
<td>No hypothesis</td>
</tr>
</tbody>
</table>
switching of crops. Better schooling is hypothesized to positively influence switching crops as it may enhance access to information along with the complementary skills of processing it (Foster and Rosenzweig, 2010; Tan, 2014; Adesina and Baidu-Forson, 1995). Access to extension services is hypothesized to facilitate any adjustment including switching crops as it avails information including on climate change (Falco et al., 2011; Maddison, 2007; Nhemachena and Hassan, 2007).

Improved access to credit has been shown to positively influence the adoption of agricultural technologies (CIMMYT, 1993; Feder and Umali, 1993). Even if switching crops is less likely to be capital intensive, it is expected that there is positive correlation between access to credit and switching crops. Access to irrigation can influence switching crops either directly by increasing the types of crops grown on a farm and potentially indirectly through its linkage with wealth. The number of relatives is used as a proxy for social capital that is expected to positively influence adjustment by switching crops. Social capital can be directly related with access to information, and facilitates learning new practices (Bandiera and Rasul, 2006). Finally, farmers in drier and hotter AEZs are more likely to take adaptation measures than those in humid climates (Deressa et al., 2009). Therefore, more cases of crop switching are expected in AEZs at lower altitudes that are characterized with relatively drier and hotter climate than those in higher altitudes (Hurni, 1998).

To summarize, the main steps involved in the method are as follows:

- The study first identifies the types of crops permanently adopted or dropped in the study area over the past two decades.
- Crop switching decisions primarily driven by climate change are disentangled based on subjective rating of farmers.
- A logit model is used to identify the determinants of adaption by crop switching. The dependent variable is whether a farmer has permanently switched crops because of climate change, i.e. a dummy variable.

### 3. Results

#### 3.1 Household characteristics and cropping pattern

The average age of the sampled household heads is 51. The majority of the respondents are male (84 per cent). An average household owns 0.95 ha of land (S.D = 0.47) and cultivates 0.98 ha (S.D = 0.5) in the Meher season, the main growing season. The total land cultivated by the sampled households in the Meher season is 185 ha, where 187 out of the 189 farmers grew at least one crop. For Belg season, only 17 ha is cultivated by 55 of the 189 farmers. The most commonly grown crop in Belg is barley followed by potato and onion, and Dega and Wurch are the main Belg producing AEZs.

The major crops grown in Meher season in Kolla and Weynadega, based on cultivated area, are teff (*Eragrostis tef*) and sorghum. Teff dominates in Weynadega, with about 60 per cent of cultivated area, whereas sorghum is slightly more commonly grown in Kolla, accounting about 42 per cent of the cultivated land. Other important crops grown in the two AEZs include mung bean and maize. The Weynadega zone also hosts crops such as wheat, barely, fava bean and chickpea. The Dega and Wurch zones’ cultivation is highly dominated by barley, which covers about 57 and 78 per cent of the land cultivated, respectively. Almost all-remaining land (19 per cent) in Wurch zone is covered by potato production. Besides barley, the Dega zone is covered with potato, wheat, fava bean and pea.
3.2 The process of crop switching

Most farmers in all AEZs in Ankober District have switched crops at least once. The highest frequency of crop switching is in Kolla, where 97.5 per cent of the respondents have made at least one type of crop switching. In the remaining AEZs, the percentage is around 80 per cent. Crop adoption took place on average 6.57 years (SD = 3.76) ago, and abandoning existing crops occurred about 7.24 years ago (SD = 4.04). Crop adoption occurs relatively recently in Kolla AEZ with average year of 3.22 (SD = 1.74), whereas it has been occurring since on average 10.87 years (SD = 2.05) in Dega. For crop abandonment, the notable inter AEZ difference is the fact that Weynadega areas are characterized with a little bit more recent adjustments, mean = 5.40 (SD = 3.03). Most farmers who adopted a new crop (67.57 per cent) did not abandon any existing crop, while the rest (32.43 per cent) had to drop at least one existing crop. On the other hand, the large majority of farmers (89.9 per cent) who dropped an old crop adopted at least one new crop.

3.2.1 Adopting new crops. The majority (95 per cent) of farmers in Kolla zone started growing at least one new crop in the past 20 years. The percentage in the rest of the AEZs is relatively lower than Kolla and ranges between 72 and 78 per cent. Few (13 per cent) farmers adopted more than one crop.

In Kolla and Weynadega, the majority (>80 per cent) of the adoptions involve mung bean (Figure 2). In Kolla, a good number (17 per cent) of farmers also started growing onion. The other crops seldom adopted in the two zones are maize, sorghum, teff and tomato.

In the Dega and Wurch zones, the most frequently adopted crop is potato, where it accounts 32 and 87.5 per cent of the new adoptions in the two zones, respectively. In Dega, the other crops adopted are beer-barley (18 per cent), cabbage (10.5 per cent) and pea (10.5 per cent). The other crops reported are apple, fava bean, wheat, onion and garlic. In Wurch zone, cabbage (8 per cent) and pea (4 per cent) are adopted by few famers.

3.2.2 Abandoning existing crops. Relatively high percentage of farmers in Kolla (65 per cent) and Weynadega (30 per cent) permanently abandoned growing existing crops at least

![Figure 2. Newly adopted crops by percentage of total number of adoptions in each AEZ.](Image)
once in the past two decades. In Dega and Wurch, however, only 7 (three respondents) and 4 per cent (one respondent) of the respondents dropped old crops, respectively. In Dega, abandoning pea and wheat were reported, while in Wurch, only one case of dropping potato was observed. To avoid ambiguity, the cases in these two zones are excluded from Figure 3. Maize is the major (57 per cent of all cases) crop abandoned in Kolla, followed by teff (30 per cent) (Figure 3). In Weynadega, fava bean accounts for 36 per cent of all crop-abandoning decisions, followed by barley (21 per cent), wheat (18 per cent) and sorghum (11 per cent).

3.3 Drivers of crop switching decisions
3.3.1 Drivers of crop adoption. Price change is the most frequently (74-89 per cent) cited primary reason for crop adoptions across all AEZs (Figure 4). Climate change is mentioned as the main driver for crop adoption only occasionally (less than 20 per cent in all AEZs). Climate change is, however, rated as the second most important driver for the majority of adoption decisions (70 per cent). The examination of drivers for each of the newly adopted crops also reveals that in general the same set of drivers influence the adoption of the most commonly adopted crops, i.e. mung bean in Kolla and Weynadega; onion in Kolla; potato in Dega and Wurch; and beer-barley in Dega.

3.3.2 Drivers of abandoning crops. Climate change is by far the most important driver of abandoning crops in Kolla (90 per cent) and Weynadega (79 per cent) (Figure 5). Pest and disease, and price change are identified as the second most important drivers. Climate change is also the major driver for the commonly abandoned crops, i.e. maize and teff in Kolla and fava bean, barley and wheat in Weynadega. Crop abandonments are rare in Dega and Wurch zones; hence, the results for these two zones are neglected. Out of the total number of farmers (44) who dropped at least one crop due to climate change, 93 per cent of them adopted mung bean, where price is the main reason for the adjustment, followed by climate change.

3.4 Determinants of crop switching
A logit model is fitted and marginal effects are estimated (Table II). The dependent variable is a dummy variable defined as 1 if a farmer stopped growing an existing crop primarily due to climate change, and 0 otherwise. The model results indicate that climate change is the most significant factor affecting crop switching decisions in both Kolla and Weynadega. The results also show that mung bean and onion are the most commonly adopted crops, followed by barley, wheat, and sorghum. The model suggests that farmers who have higher income and access to credit are more likely to adopt new crops. The model also indicates that the adoption of new crops is influenced by the availability of new crop varieties and the extension services provided by the government.
Figure 4. Drivers of crop adoption decisions across AEZs

Notes: hhld = household; n stands for the number of switching decisions in each AEZ: it can be larger than sample size as some farmers switched crops more than once

Figure 5. Drivers of new crop abandonment decisions across AEZs

Notes: hhld = household; n stands for the number of switching decisions in each AEZ: it can be larger than sample size as some farmers switched crops more than once

<table>
<thead>
<tr>
<th>Determinants</th>
<th>Crop switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of the household head in years</td>
<td>−0.001</td>
</tr>
<tr>
<td>Land owned in ha</td>
<td>0.094**</td>
</tr>
<tr>
<td>Family size</td>
<td>−0.001</td>
</tr>
<tr>
<td>Walking distance from market in hours</td>
<td>0.017</td>
</tr>
<tr>
<td>Level of education (dummy, 0 if illiterate and 1 otherwise)</td>
<td>−0.061</td>
</tr>
<tr>
<td>Access to extension services (dummy, 0 if without access, and 1 otherwise)</td>
<td>0.053</td>
</tr>
<tr>
<td>Access to credit (dummy, 0 if without access, and 1 otherwise)</td>
<td>0.034</td>
</tr>
<tr>
<td>Access to irrigation</td>
<td>−0.058</td>
</tr>
<tr>
<td>Number of relatives in village</td>
<td>0.001</td>
</tr>
<tr>
<td>AEZ (ordinal, 1 if Kolla, 2 if Weynadega, 3 Dega, and 4 Wurch)</td>
<td>−0.190***</td>
</tr>
</tbody>
</table>

Notes: ** and *** respectively indicate level of significance of 5% and 1%
to climate change, and 0 otherwise. As climate change is not strongly associated with adopting new crops, the analysis is confined to only crop abandonment. Out of the 189 households finally included in the analyses, 44 (23 per cent) dropped at least one crop primarily due to climate change.

The logit model has a very good overall model fit shown by Likelihood ratio test [LR chi2 (10) = 71.82, \( p < 0.01 \)] (Table II). Wald statistic also confirmed the same [chi2 (10) = 31.51, \( p < 0.01 \)]. Classification test showed that the model correctly specifies 82 per cent of the time for a cutoff point of 0.5. AUC is 0.88, indicating a high predictive accuracy of the model. VIF values range between 1.13 and 1.45, which indicated the absence of any important multicollinearity problem. Land size and AEZ are the only variables that are significantly related to crop switching. Land size is positively related to crop switching. A one-hectare change on average is expected to increase the likelihood of adaptation by crop switching by 9.4 per cent. The influence of AEZ is more pronounced where a shift to a higher altitude zone (i.e. from Kolla to Weynadega, for example) is associated with about 19 per cent decline in the likelihood of adaptation by crop switching.

4. Discussion
The study revealed that considering crop switching as an adaptation strategy without narrowly defining it could be misleading. For our case study, only crop abandoning is associated to climate change, while the adoption of new crops is primarily motivated by price changes. This is a new finding which challenges the results of most previous studies that considered crop switching at aggregate level or under a general heading of crop switching without separately considering the different types of switching decisions (Maddison, 2007; Bryan et al., 2009; Gbetibouo, 2009; Deressa et al., 2009). The particular relevance of abandoning crops to climate change also suggests that farmers initially take more risk-averting measures to adapt to climate change.

Empirical evidences from studies on crop-distribution modeling and ecological change further validate the findings. In Kolla (lowland) and Weynadega (middle land), of the study area, a significant number of farmers shifted away from crops (teff, maize, fava bean, barley and wheat) that are typically grown at higher altitudes, in relative terms to the particular AEZ considered (Hurni, 1998). This is what is expected as a warming climate shifts agroecologies toward drier classifications (Kala et al., 2012), or in upward direction for elevational range-shifts (Mekasha et al., 2013). Furthermore, the result on the abandonment of maize is in line with the results of crop-distribution modeling by Rippke et al. (2016). According to this study, the suitable climate space for maize in sub-Saharan Africa is shrinking, and 30 per cent of the currently cultivated area may become unviable by the end of this century. Ethiopia is one of the regions that is affected by this particular change (Rippke et al., 2016). The decline of land allocated to barley production, one of the abandoned crops, in Ethiopia has also been reported (Rashid et al., 2015). The fact that crop abandonment is rare in higher altitudes (Dega and Wurch) could be related to the fact that already hotter and drier climates are likely to strongly feel climate change than cooler and wetter areas (Deressa et al., 2009). Furthermore, the finding may be attributed to the positive influence of non-climatic drivers that offset the effect of climate change. For example, abandoning barley in higher altitudes may be delayed due to price increase in relation to flourishing beer factories in the vicinity of the study area, which is actually the case in the study area. This issue, however, needs further empirical investigation.

The importance of market dynamics in the adoption of the commonly adopted new crops in the study area, i.e. mung bean and potato, is also well supported. Mung bean is a cash crop that is in recent times enjoying high increase in price due to rise in export demand (Seyoum, 2014).
Besides its market advantages, the crop possesses favorable characteristics of short growing period and suitability for semiarid climate (Beshah, 2015). Similarly, potato is one of the fastest expanding crops in the country owing to its nutritional advantage, increasing local demand and short growing season (Emana and Nigussie, 2011; Haverkort et al., 2012).

To sum up, farmers in Kolla (lowland) and Weynadega (middleland) switched away from crops such as maize and fava bean primarily due to climate change, and a large majority of them have adopted mung bean for which price is the main driver followed by climate change. This demonstrates the importance of opportunities, in this case favorable price, in adapting to risks. The adoption of mung bean is an opportunity created due to export market linkage, yet its agronomic qualities makes it an ideal candidate to adapt in climate change. The fact that farmers rated climate change as the second important driver next to price supports this argument.

This study examined the determinants of adaptation by crop switching. Land size and AEZ are significantly correlated with adaptation by crop switching. Farmers with bigger land are found to be more likely to switch crops as a response to climate change. Larger land may allow experimentation with different crops that facilitates appropriate switching. The finding could also be associated with the general correlation of land size with wealth as it represents a major asset of a smallholder farmer. The importance of land size in farm-level adaptations has been shown by a number of studies in the past (Alauddin and Sarker, 2014; Nhemachena and Hassan, 2007). The inverse relationship of adaptation by crop switching to AEZ (ordered altitude wise) is also in line with the findings of previous studies. It has been shown that farmers in drier and hotter climate zones are more likely to take adaptive measures (Deressa et al., 2009).

The interpretation of the results should, however, be made keeping some conditions in perspective. The first is the design of the sampling that selected a study area that shows variations in AEZs within a short distance. Such design is likely to include the borders of the climate spaces of various crops, which are the frontlines of shifts in crop mixes as the climate changes (Cho and McCarl, 2017). Hence, it is probable that this type of sampling design reveals more switching decisions than could have been otherwise. Moreover, the study area, Ankober District, located 40 km to the nearest asphalt road/major town, is by Ethiopia standard (Schmidt and Kedir, 2009) relatively close to a major urban center. The importance of market changes are, therefore, more likely to have a pronounced effect in the district. Finally, this study used a sample size of 190, which is big enough for the carried out analyses but can be considered small relative to several studies in the literature. The results should, therefore, be interpreted in light of this fact, and the research problem can highly benefit from future studies.

The major policy implication of the study is that adaptation through crop switching is better facilitated taking into account opportunities in the environment. The specific case of mung bean can serve as a classical example of how farmers can adapt to climate change through adjustments that are primarily motivated by opportunities. Moreover, the risk-averting behavior of smallholder farmers in low-income countries (Hamal and Anderson, 1982; Yesuf and Bluffstone, 2009) could confine their adaptation responses to crop abandonment, at least initially. This may call for appropriate mechanisms that facilitate other complementary adjustments. On the other hand, the findings revealed the strong correlation of the process of adaptation responses to agroecology and implied the need for spatially cautious adaptation planning. Especially in mountainous countries such as Ethiopia, where there is high agroecological diversity, a detailed spatial planning of adaptation could be vital.

5. Conclusions
The main objective of the study is to disentangle specific group of switching decisions that are primarily motivated by climate change and the socio-economic and environmental
factors that influence them. The study shows that farmers in relatively drier and hotter AEZs are currently abandoning existing crops such as maize and fava bean as a response to climate change, and the adoption of new crops is primarily induced by price changes. The crop abandonment trend is in line with the predictions of ecological studies and crop-distribution modeling, which further validates the findings. The fact that abandonment rather than adoption is associated to climate change may also indicate the risk-averting behavior of smallholder farmers. Most farmers who abandoned existing crops because of climate change adopted a cash crop (mung bean) primarily due to price increases for the crop because of new linkage to export market. The adoption of the cash crop is secondarily motivated by climate change, as it is evident in its agronomic qualities, and farmers’ subjective assessment. The most important determinants of crop switching are land size and agroecological factors.

References


Ege, S. (2005), Topographic and Administrative Map of North Shawa Zone, Amhara Region, Ethiopia, Department of Social Anthropology, NTNU, Trondheim.


**Corresponding author**

Yibekal Abebe Tessema can be contacted at: yibekalab@yahoo.com

For instructions on how to order reprints of this article, please visit our website: [www.emeraldgrouppublishing.com/licensing/reprints.htm](http://www.emeraldgrouppublishing.com/licensing/reprints.htm)

Or contact us for further details: permissions@emeraldinsight.com
Disinterested agents or mismatched plans?
Public administration capacities and climate change responses in the least developing countries

Sunil Tankha
International Institute of Social Studies, Erasmus University Rotterdam, The Hague, The Netherlands, and
Sunita Ranabhat, Laxmi Dutt Bhatta, Rucha Ghate and Nand Kishor Agrawal
International Centre for Integrated Mountain Development, Kathmandu, Nepal

Abstract
Purpose – Developed countries agreed at COP15 to pay US$100bn annually for adaptation and mitigation in developing countries. This paper aims to evaluate how prepared are donors and recipients to spend this money well by analyzing institutional and organizational capabilities for climate change adaptation in least developed country (LDC) administrations using the case of Nepal, a country which can be considered to be an archetypal LDC.

Design/methodology/approach – The authors conducted over 100 in-depth structured qualitative interviews with government officials from across the organizational chain in the ministries concerned with climate change, ranging from the lowest-ranked employee to just under the ministerial ranks. This was supplemented with detailed surveys of three representative communities from different ecological zones in Nepal. Data were analyzed using Ostrom’s IAD framework.

Findings – Local administrations are more motivated and capable than are given credit for by donors but nevertheless face critical barriers in being able to function autonomously and confront climate change challenges. These barriers create three interrelated challenges: An organizational challenge to create intrinsic incentives which empower and grant autonomy to front line agents, an institutional challenge to go beyond accountability-focused process validation and a policy-choice challenge which avoids the temptation to write aspirational policies without clear and feasible strategies to obtain the resources necessary for their implementation.

Practical implications – The findings point to ways climate assistance can be restructured for more reach and effectiveness.

© Sunil Tankha, Sunita Ranabhat, Laxmi Dutt Bhatta, Rucha Ghate and Nand Kishor Agrawal. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licenses/by/4.0/legalcode

This paper was developed as part of the Himalayan Climate Change Adaptation Programme (HICAP). HICAP is implemented jointly by the International Centre for Integrated Mountain Development (ICIMOD), GRID-Arendal and the Centre for International Climate and Environmental Research-Oslo (CICERO), in collaboration with local partners, and is funded by the Governments of Norway and Sweden.
Originality/value – This paper fills a gap in the literature because community structures and institutions have been extensively analyzed in the context of adaptation, but despite being criticized, administrative structures have rarely been directly studied.

Keywords  Agriculture, Nepal, Donors, Public administration, Forestry, Climate change adaptation

Paper type Research paper

1. Introduction
At the Copenhagen Conference of Parties (COP15) in 2009, developed countries committed to funding (by 2020) climate change mitigation and adaptation efforts in developing countries to the tune of US$100bn annually. While the modalities of climate finance are still being worked out – there are debates about the relative amounts of funds which should come out of the public and private sectors and about the relative amounts which should be spent on adaptation and low-carbon development – the least developed countries (LDCs) have already started receiving substantially increased flows.

Our paper stems from concerns about the effectiveness of these expenditures, and it investigates the challenges faced by donors and local administrations in the LDCs to spend this money well. We address this issue using the case of Nepal, which can be considered to be an archetypical LDC with problems associated with internal socio-ethnic cleavages, weak government, political conflict and uncertainty, severe organizational resource constraints and, of course, widespread poverty. Our analysis, grounded in the case and based on over 100 in-depth structured qualitative interviews with government personnel from across different organizational chains as well as detailed surveys of three representative communities, identifies the critical barriers government agencies face in being able to function autonomously and confront the challenges of climate change. By providing a comprehensive empirical analysis of the institutional and organizational capabilities for climate change adaptation in the public sectors, we address critical questions about whether and how LDCs can absorb more donor funding and about the risks and returns involved.

This research fills an important gap in the literature. While the concept of adaptive capacity has been in conceptual and theoretical development for decades, the empirical examination of such capacities is still scarce (Lemos et al., 2013). The IPCC had noted that in contrast to the scientific research on natural systems, research on social systems and institutions is not as voluminous. Partly because of this, adaptation concerns have been discussed and dissected much less than mitigation ones (IPCC, 2007; Klein et al., 2005) leading to an ongoing challenge in the development of practicable knowledge about climate change adaptation. Fortunately, over the past few years, a substantial literature has begun to emerge on adaptation issues, which is both theoretical (Folke, 2006), and place-based (Goldman and Riosmena, 2013; Jones and Boyd, 2011). Most of these studies, especially in developing countries, have initiated the research agenda by focusing first on communities. Government and administrative structures have not yet been extensively analyzed. Even many critiques of administrative structures, for example the case of forest rights in Springate-Baginski et al. (2013), have generally reported from the communities’ points of view without performing an institutional or organizational analysis of the bureaucracies themselves. Meanwhile, most of the information available about the public sector and climate expenditures in the LDCs is anecdotal. By formally investigating public administration, our paper complements the research on local community-based institutions for climate change adaptation.

In Nepal too, there are no comprehensive analyses of public administrations and climate change or about how these institutions and corresponding organizations are responding to
climate challenges. Among the existing studies, Yates (2012) found that institutional responses to vulnerability are highly variable, depending often on physical distances from decision-making structures. In his analysis, vulnerability is a representational issue. Jones and Boyd (2011) analyzed how embedded social processes create discriminatory practices based on caste and gender which are barriers for adaptation action. Other studies such as Onta and Resurreccion (2011) focused on elite control and gendered responses to adaptation capacities in Nepal, shedding light on problems with a broader distribution of entitlements. From these studies, we can conclude that community-based institutions are prey to traditional social and ethnic cleavages, but still none of these studies engaged with wider sets of the relevant structures of public action, such as government and administrative organizations, to see whether the latter were more or less subject to these cleavages.

In the absence of such studies, the public sector is usually caricatured in Nepal and elsewhere as incapable, unmotivated and rent-seeking and little effort is made either to understand the constraints under which the public sector operates or to theorize on how to leverage its existing resources for climate change adaptation. Thus, while they are arguably among the most important institutions in the development and environment spheres, public sector organizations in developing countries have often remained a bystander in climate adaptation initiatives. In an analysis of 118 adaptation cases drawn from the United Nations Framework Convention on Climate Change (UNFCCC) database, Agrawal (2010) finds that in the overwhelming majority of cases (102 out of 118) civic organizations worked alone in facilitating adaptation to climate change, while public organizations working alone figured in only six cases. The dominance of civic organizations in this arena can be explained mostly by the centrality of donor funding for climate change adaptation in the LDCs which tends towards contracting NGOs and CSOs to conduct project-based adaptation activities but while these may have several advantages vis-à-vis the public sector, notably in the spheres of probity and attitudes, the former also suffer from several critical limitations – particularly in terms of territorial reach, funding dependence, continuity and a programmatic focus – and it should not be expected that they can credibly supplant the latter in achieving long-term transformative goals based on, as Banks et al. (2015) put it, their success in service delivery projects of modest and discrete scale.

2. Conceptual approaches to investigating institutional and organizational capabilities for climate change adaptation

2.1 Spheres of adaptation action: a focus on livelihoods

Adaptive capacity is generally understood to mean the ability of a community to deal with its vulnerability to exogenous shocks and maintain its viability and welfare. It is known to be a function of both the resources available to the community and the decision-making processes through which a community distributes and expends these resources in anticipation of or in reaction to a shock. The relevant resources include productive and financial assets as well as knowledge and practices.

Adaptation initiatives and research in the LDCs usually focus on livelihood strategies (Paavola, 2008; Chhatre and Agrawal, 2009). This approach operates under the assumption that vulnerability is a function of the available livelihood options (Jodha, 2005) and that the poor are especially vulnerable to environmental shocks because of their dependence on natural resources for subsistence and income (Agrawal and Perrin, 2009). Although Agarwal (2010) argues that development and adaptation are two separate conceptual spheres because the latter is explicitly focused on being able to deal with unpredictable variations in outputs rather than on reducing poverty levels, the two are closely intertwined because poverty limits the investments a community can make in protective and productive
infrastructure and the buffers that it can accumulate for dealing with shocks. Moreover, there is a large body of literature which argues for mainstreaming climate change adaptation and risk management into developmental processes (Huq et al., 2004). In the case of Nepal itself, for example, Biggs et al. (2013) found that most adaptation strategies in the agricultural sector were developmental. Thus, even if the concepts of development and adaptation are distinct, they are objectively linked in poorer societies and the institutions and organizations which deal with livelihood, development and climate change are the same or work in overlapping spheres, even if they do not always collaborate.

In sector-specific terms, grounded research on adaptation action generally focuses on a well-known set of productive sectors. In the case of Nepal, the relevant sectors are identified by its UNFCCC mandated National Adaptation Plan of Action (NAPA) as forests and agriculture. The research agenda in both these areas is well-developed, and the literature available in these arenas informs the kinds of adaptation action which are needed and the roles public agencies may need to play in these arenas.

2.1.1 Forests. In the case of forests, there is an extensive literature linking livelihoods and conservation, but the assumption that there is a win-win between conservation and poverty alleviation does not find unequivocal evidence (Sunderlin et al., 2005; Agrawal and Redford, 2006) and the outcomes seem to depend strongly on contextual factors (Persha et al., 2011). Nevertheless, forests do play a role as a shock-absorber which makes it directly relevant from an adaptation perspective.

A major shift in forestry management in developing countries over the past few decades has been the progressive devolution of rights and responsibilities to the communities which live in and around these areas. Many legislative battles and community struggles have been extensively documented and the outcomes of community forestry have also been comprehensively studied, the conclusions being generally favorable though cautious. The logic of community forestry is based on virtuous local collective action, but while the conditions for ensuring these virtuous structures might sometimes appear spontaneously, in the majority of cases where they do not quite some social engineering is required because of the number of variables involved for successful community action, by one count (Agrawal, 2001) over 30.

The literature thus presents the key challenges of forestry from a livelihoods perspective as to first ensure that forest resources are protected for the local communities and then at a subsequent stage to ensure that these resources are exploited to create community assets and income opportunities rather than rents. Insofar as using forest resources for sustainable livelihood generation is concerned, researchers have found that in Nepal forests currently contribute only between 3 to 11 per cent of total income for the poorest forest dwellers even as many forest areas in the plains and high mountains are still underutilized, indicating that allowing more commercial timber harvests could be a win-win opportunity (Meilby et al., 2014). However, they do not address the institutional requirements or change processes that might be needed to introduce desirable flexibility in forest management. Meanwhile attempts by the state to reassert some degree of control over the forest are severely opposed and criticized (Sunam et al., 2013), indicating that there are contentious political issues which need to be resolved.

2.1.2 Agriculture. In the case of LDCs, the relevant unit of analysis of agriculture from an adaptation perspective is the smallholder farm. The Food and Agriculture Organization (FAO) estimates that over 98 per cent of all farm holdings worldwide are family-based and indeed most adaptation projects in Nepal also deal with communities where small holder farming is the dominant mode of production. Here, there is an extensive literature which, arguing that more research and development on its own now has limited potential for
increasing productivity and well-being, engages with the issue of inserting small family farms into more commercial value chains as a means of agricultural development (Lowitt et al., 2015), thus combining the push of agricultural extension work with the pull of market networks. These chains include not only the more sophisticated and widely reported-on global value chains but also those between rural communities and local markets. Another stream in the literature on rural livelihoods emphasizes the importance of income diversification strategies to both increase and smooth net incomes, mirroring in a sense the advice given to investors on portfolio diversification. This presents an intriguing challenge because some researchers have identified dueling arguments on the competing benefits accruing from specialization and diversification, pointing to how value chains may undermine traditional diversification practices through a greater emphasis on market relations (Jodha, 2005).

While the literature and the associated debates indicate the need for a more intensive accompaniment of agricultural development in the most vulnerable areas to coordinate insertion and diversification, the role of the state and public sector organizations has been underappreciated in the resilience literature. The main challenges to rural development which have been identified so far, including land tenure, finance, economic scale and productivity, clearly argue that beyond a few project-based initiatives, only the public sector is potentially capable of addressing these at a regional scale. The alternative, of course, is that market forces will shape these spheres in their own inimitable way where the outcomes can be positive but in reality have so far have usually been problematic for vulnerable communities and groups, especially women (Chege et al., 2015; Wood, et al., 2013). While much adaptation work is still not routed through the government, some have started to recognize that international organizations and donors were wrong in promoting a reduced public sector role in agricultural development (FAO, 2013).

In Nepal, as agriculture still represents 34 per cent of economic production and as 81 per cent of the population still resides in rural areas and depends at least partly on agriculture[1], the potential effect of climate change on agriculture is a significant threat to well-being. Climate models suggest that although the total amount of water available for agriculture may not decrease in Nepal – with increased snow-melt balancing more irregular monsoons and increased evapotranspiration – increasing variability of weather punctuated by potentially more frequent natural calamities may have serious consequences on crops (Eriksson et al., 2009). Climate change impacts are already visible in agriculture, with both positive and negative effects. On the positive side, increasing temperatures allows crops to grow at higher altitudes and for longer periods. On the negative side, farmers report production at lower altitudes is suffering from more irregular water availability, increased pest attacks and heat damage, both phenomena requiring place-based interventions.

3. Methodology
As our objective is to provide a structural-institutional perspective on the organizational performance for managing climate challenges in Nepal, we study the effects both of formal rules and regulations, and of organizational structures and organizational capacities on decision-making in communities and administrative agencies. In our study, we make a distinction between organizations and institutions. We treat the former as constellations of agents with both a common purpose and individual interests, while we approach institutions as the formal and informal, written and customary rules and ways of behavior which guide decisions in defined arenas. Thus, unlike many other scholars, our approach classifies the various ministries as organizations because we are more focused on their interests and motivations, while we treat the community forest users groups (CFUGs)
described below as an institution because we are more interested in how rules affect the decisions taken within them. This is also consistent with the approach in Ostrom’s Institutional Analysis and Design (IAD) framework. This framework allows researchers to organize “diagnostic and prescriptive inquiry” by identifying the major types of structural variables in a multi-tier conceptual map (Ostrom, 2011, 2007). IAD, in particular, developed the concept of an action arena – consisting of an action situation and actors – within which the researcher can study the way relevant variables interact to determine actors’ decisions and the outcomes which result. It has been used in a variety of resource-use settings ranging from fisheries management (Imperial and Yandle, 2005; Rudd, 2004) and land-use planning (Pethe et al., 2012) to co-management (Whaley and Weatherhead, 2014).

We use this framework for our research, defining the action arenas that are most relevant to studying Nepal’s responses to climate change and then studying their operational rules and organizational resources to understand the nature of the spaces within which decisions about resource use and livelihood planning under climate change pressures are taking place.

3.1 Case selection
Sandwiched between the Tibetan Plateau and the Gangetic Plains, Nepal is divided roughly evenly among the high mountains, middle hills and the plains forests. For our study, we selected three rural districts (based on suggestions by relevant stakeholders) representative of each of these geographic zones to incorporate variation in remoteness and community structures (Table I; Figure 1)[2]. In each of the districts, we concentrated on two action arenas which were identified by Nepal’s NAPA and other stakeholders as being especially relevant to adaptation activities: forest management and agricultural development. The apex ministries in these arenas are the Ministry of Forests and Soil Conservation (MoFSC) and the Ministry of Agricultural Development (MoAD). As indicated in Nepal’s NAPA,

<table>
<thead>
<tr>
<th>Item</th>
<th>Plains/Terai</th>
<th>Middle hills</th>
<th>High mountain</th>
</tr>
</thead>
<tbody>
<tr>
<td>District name Location (Province)</td>
<td>Chitwan Central Development Region</td>
<td>Gorkha Western Development Region</td>
<td>Dolakha Central Development Region</td>
</tr>
<tr>
<td>Main livelihoods</td>
<td>Agriculture, livestock, poultry, wage/salary,</td>
<td>Agriculture and livestock, foreign employment, daily wage labor</td>
<td>Agriculture and livestock, businesses, government jobs</td>
</tr>
<tr>
<td>Total area</td>
<td>2238 sq. km</td>
<td>3610 sq. km</td>
<td>2191 sq.km</td>
</tr>
<tr>
<td>Poverty Rate</td>
<td>8.89%</td>
<td>20.41%</td>
<td>25.90%</td>
</tr>
<tr>
<td>Population</td>
<td>579,984</td>
<td>271,061</td>
<td>186,557</td>
</tr>
<tr>
<td>GDP (in million US$)</td>
<td>338.98</td>
<td>106.72</td>
<td>65.34</td>
</tr>
<tr>
<td>Infrastructure and accessibility</td>
<td>88.90 km national highway, 83.49 km feeder road and 61.00 km postal road</td>
<td>279.24 km feeder road and 31 km mid hills road</td>
<td>258.75 km feeder road</td>
</tr>
<tr>
<td></td>
<td>96.2% of households have improved source of drinking water</td>
<td>65.4 % of households have improved source of drinking water</td>
<td>78.5% of households have improved source of drinking water</td>
</tr>
<tr>
<td></td>
<td>94.1% of households have toilet facility</td>
<td>73% of households have toilet facility</td>
<td>69.5 % households have toilet facility</td>
</tr>
<tr>
<td></td>
<td>86.3% of households have electricity for lighting</td>
<td>76.7% of households have electricity for lighting</td>
<td>82.1% of households have electricity for lighting</td>
</tr>
</tbody>
</table>

Source: Adapted from: GoN (2013, 2014a, 2014b and 2016a)
several other ministries and departments are also relevant for a more complete approach to climate change management but a scoping exercise we performed determined that a more comprehensive treatment including these other organizations would be mostly duplicative.

3.2 Data collection and analysis
We conducted over 100 hour-long structured open-ended interviews with government officials from across organizational chains in the concerned ministries as well as with villagers, quizzing them on climate change knowledge, policies, administrative conditions and community decision-making structures. The interview questions for government officials varied slightly based on the rank of the interviewee while those for villagers were standard. In the villages, we purposively interviewed both men and women, those from different castes, and community members who were active in community decision-making structures and those who were merely passive participants. Some of the enquiries were of a sensitive nature, so sometimes we used multiple questions with different phrasings to enable triangulation. Data collected were analyzed mostly qualitatively in the manner in which Feldman et al. (2004) described as beneficial for studying public administration, i.e. in using events, experiences and actions to understand a meaningful whole.

4. Arenas for climate change adaptation action
Here, we discuss the critical institutional and organizational dynamics we found in the selected action arenas and make some concluding observations which indicate the areas of particular concern to climate adaptation interventions. The aggregate table of IAD findings using its formal terminology is presented below and followed by a discussion of the salient observations. This table and the discussions following clearly show that authority and aggregation rules are oriented toward validating processes rather than developing livelihood-based solutions to addressing climate challenges (Table II).

4.1 Forest management
About half of Nepal’s forests are under traditional government management, while about 34 per cent are under community control. National Parks areas, which are under special management systems, make up 17 per cent of the country’s forest areas. Private forests are
<table>
<thead>
<tr>
<th>SN</th>
<th>Rule</th>
<th>Explanation of rule</th>
<th>Forest management</th>
<th>Agricultural development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Position rules</td>
<td>The roles and types of positions that participants can assume in an action situation</td>
<td>Decision-making positions in CFUG open to all community members</td>
<td>Farmers typically assume passive recipient role vis-à-vis agricultural extension workers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mandatory representation quota for women and disadvantaged</td>
<td>Agricultural department workers position of authority with respect to rationing their services</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Forest department officials prepare the plans which guide how much forest resources, esp. timber can be harvested</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Politicians have informal access</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Boundary rules</td>
<td>Rules for entry to and exit from a position in an action situation</td>
<td>Access to CFUG management positions by community consensus</td>
<td>For marginal farmers, outmigration or local service sector jobs (scarce)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Forest department personnel posted for average tenure of 3 years</td>
<td>Government personnel routine transfers</td>
</tr>
<tr>
<td>3</td>
<td>Scope rules</td>
<td>Designation of areas to which rules apply (Jurisdiction)</td>
<td>Community forestry rules apply to 34% of national forests</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Direct MoFSC administration over 49% of national forests</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Special protected forest rules apply to 17% of national forests</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Choice rules</td>
<td>Actions participants may perform</td>
<td>CFUGs may decide on allowable cut, royalties, but in reality operational plans heavily influenced by MoFSC staff</td>
<td>Agricultural extension agents have broad latitude in deciding to whom to offer services</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Agricultural agents have no choice with regards to which services to provide</td>
</tr>
<tr>
<td>5</td>
<td>Information</td>
<td>Quantity and type of information available to participants</td>
<td>Little concrete information about forest inventory and condition</td>
<td>No information available to community members about available funds for agricultural extension activities</td>
</tr>
<tr>
<td></td>
<td>rules</td>
<td></td>
<td></td>
<td>(continued)</td>
</tr>
</tbody>
</table>

Table II. Action situations and rules analysis
### Table II.

<table>
<thead>
<tr>
<th>SN</th>
<th>Rule</th>
<th>Explanation of rule</th>
<th>Forest management</th>
<th>Agricultural development</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Payoff rules</td>
<td>Rewards and punishments, or costs and benefits obtained from sets of actions</td>
<td>Monitoring done by community</td>
<td>For Agricultural department staff, less work pressure if they provide services to those expressing demand (better-off community members) than focusing on those who require more attention (the disadvantaged groups)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Official sanctions against offenders light and unreliably (rarely) administered</td>
<td>Assistance provided to better off members using <em>logic of convenience</em>. High levels of dissatisfaction with agency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Social sanctions light for both elite offenders (because of status) and poor offenders (because of need)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Aggregate rules and outcomes</td>
<td>Focus on subsistence-level extraction and conservation and rather than livelihoods generation</td>
<td>Tendency for community members to illegally extract from government managed forests where enforcement is non-existent rather than CFUG managed forests</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No transformation of livelihood opportunities</td>
<td></td>
</tr>
</tbody>
</table>
negligible. With the 1993 Forest Act and the 1995 Forest Regulations, government-managed forests were increasingly transferred to community control exercised by CFUGs, and it is expected that this trend will continue.

CFUGs are broad-based organizations open to all community members who make collective decisions over levels of extraction of forest products, especially timber, and formally have collective responsibilities for determining extraction, distribution and maintenance of forest resources. They raise money from forest product royalties and membership dues and spend them on community infrastructures and other social and development programs.

CFUGs have clear rules regarding the composition of their management committees, which includes mandatory representation of women and disadvantaged groups. Representation does not of course guarantee genuine participation. Responses to the question on who speaks the least in meetings generally showed that it was women and ethnic minorities or the Dalits. But while the observation of one woman in the CFUG that she was in the committee only “to fulfill the quota of women” is an accurate characterization of the nature of many women’s involvement in community management structures, it is not the only type of outcome. A few women who have participated in these committees report greater and continuing awareness and involvement in community resource management. The results in terms of the empowerment of disadvantaged groups are therefore varied and often depend on idiosyncratic factors like strength of personality. Nevertheless, the space created by CFUGs is progressively lowering the bar for genuine participation of disadvantaged groups.

Our question to community members as to who benefits the most from CFUGs elicited an interesting contrast. While some of the poorer respondents indicated that the wealthier benefitted more because they were able to purchase more of the timber on offer by the CFUG, some of the better-off respondents as well as some of the poorer ones responded that the weaker groups benefitted more because the CFUG royalties funded earmarked benefits such as scholarships for poor children. This indicates that certain protocols have the effect of establishing and at least minimally safeguarding entitlements for the weakest community members. So while we can confirm the distributional biases in CFUGs found by others (Iversen et al., 2006), we can also see that the biases do not completely erode the entitlements.

While some rules of community forest management, such as those related to representation, have contributed to better securing economic entitlements for the poorest, others have prevented community forests from playing a significant role in local economic growth. Rules guiding CFUG management allow only subsistence-level of timber extraction by community members. A typical family, we were told, might collect 30 kg of firewood and 210 kg of fodder per week, in addition to about 50 cubic feet of timber for house construction or repair when required. This is not insignificant, but certainly it is too little to transform livelihoods. Although the CFUGs do charge royalty for timber, the allowed cut is rather small. Our findings thus reflect the consensus among many researchers (Meilby et al., 2014) that forests in Nepal are underused, even though there is persistent demand for more timber.

Almost all administrative agency respondents pointed out severe resource constraints in personnel, equipment and funds to execute mandated tasks. These inhibit MoFSC staff’s ability to enforce rules related to forest encroachment and timber smuggling. Field level staff repeatedly indicated that they cannot prosecute offenders. As one Ranger put it, “we don’t even have a vehicle to take the offender before a judge.” Even if the vehicle were available, local politicians almost always intervene to ensure that cases are never brought before a judge. Enforcement is therefore limited to at most confiscating the timber or temporarily impounding cattle grazing without a permit (though these are quickly released
as the forest department would otherwise have to itself provide fodder for these animals). But most breaches are never detected. As one Ranger noted, he has to look after 58 forest parcels and, lacking transport, does not visit most of them. Similar limitations also prevent MoFSC field staff from carrying out accurate and complete forest inventories. Indeed, when questioned about which tasks they are not able to perform because of resource limitations, the most common answer was forest inventory and management, which is their primary responsibility. Instead, managing CFUG affairs took up most of their time.

This is one of the main reasons behind the failure to develop strategies for employing forest resources to transform livelihoods. Governance structures are partly responsible for the rules which result in low economic activity around forest products. Transfer of forests to the CFUGs does not remove the MoFSC from the picture. CFUG protocols, heavily tutored by donors whose focus was more on conservation, require preparation of forest management plans which include basic inventorying for determining sustainable harvest levels, and it is the local staff of the MoFSC which prepare these plans. Indeed, much of the time of the field staff of the MoFSC goes into preparing these plans and because it is an administrative requirement, the preparation of the plans takes precedence over on-the-ground activities such as patrolling. However, the plans are often ritualistic for even the basic inventorying of the forest which is required to prepare them is usually not done because of manpower and basic equipment shortages. Without an adequate inventory, an increase in forest exploitation can be risky. The conservationist approach followed by the forest staff is justified to some extent because a permissive management approach would require monitoring capabilities which are beyond the reach of the MoFSC and therefore almost blanket-bans are necessary to simplify the task environment. Our respondents indicated that the prohibitive bias and administrative restrictions and regulations in the management of community forests prevent most forms of economic exploitation, and this extends even to the few tracts of private forests. Such approaches result in little being done for forest-dependent communities beyond safeguarding subsistence level entitlements and forest conservation.

Resource limitations also affect staff motivation. We gathered from interviews that MoFSC staff believes itself to have technical skills in forest management issues and regret that they are unable to practice what they refer to as Scientific Forest Management (SFM). While they rarely have the time or the equipment to perform the tasks that validate them professionally, they are also squeezed by community demands for which they are also unprepared. One Ranger explained “Forest users do not want to upgrade the regulations. The want us to do it, but we have enough budget only for preparing the operational plan.”

Organizational theory posits that resource constraints generally lead to conflict and in this environment we would expect to find a strained relationship between forest staff and communities, but our findings are more nuanced. The literature from India, for example, claims that forest bureaucracies actively resist community rights (Matta and Kerr, 2007; Kumar and Kant, 2005). In Nepal, however, the forest staff has a more balanced view on the matter. Almost everyone interviewed expressed themselves in favor of community forest management and said they had good relations with the CFUG despite also reporting that there are frequent conflicts with the community. They recognized that they lacked the ability to adequately patrol and protect the forests and that community management reduces the number and extent of local level violations but they also remarked that community members (and this was confirmed by the villagers) now tended to exploit state forests more.

Where conflicts with communities did arise, forest department officials said they were a result of community members attempting to extract more than what CFUG operational
plans allow them to and these, the forest staff responded, are resolved by explaining the rules to the community and, often, involving the local politicians to intercede. We also enquired from community members as to who breaks the rules. Rather than point to the existence of some timber mafia, we were told that it is the poor who most often break the rules because they extract firewood to sell and supplement their meager incomes. This also explains the reluctance of forest staff and CFUG management committees to strictly enforce rules.

4.2 Agricultural production
Economic conditions underlying Nepal’s agriculture are challenging. In all the three sites we visited, production of staples such as rice and maize was at subsistence levels and even though there is potentially productive land lying fallow (about 10 per cent according to several respondents) and a preference for local varieties, unavailability of labor because of outmigration and inability to compete on price terms with imports because of insufficient capital inputs are substantial barriers to accessing markets[3]. Production of staples is nevertheless an important source of consumption in what are essentially cash-poor local societies and so to climate-proof farming is an imperative.

Unlike the CFUGs in forestry, agriculture in Nepal has no dedicated community deliberative space. The local agricultural technicians are under the District Agricultural Development Office (DADO) and in most cases villagers must approach DADO directly for access to programs and benefits. Here, there are no clear rules regarding agricultural program entitlements, as these vary from program to program and most farmers interviewed reported little familiarity regarding these entitlements.

Resource limitations are more keenly felt in agricultural extension than in forest management. Diffusing knowledge and innovation on how to deal with climate change is labor intensive and requires personal visits to individual households and hamlets over an extended period. Junior Technical Assistants (JTAs), the field-level agricultural extension workers, felt it physically impossible, given current staffing levels, to engage with the farmers to the extent which is necessary to spread knowledge and innovative practices.

As a result of resources limitations, JTAs gravitate toward providing services to the less vulnerable middle status farmers, even though the official policy is to prioritize poorer and backward classes. When queried about which persons most use their services, the JTAs indicate that middle class farmers who are “more likely to help themselves” and to “continue to follow the program and instructions.” According to one JTA from Gorkha, only 10 per cent of farmers are interested in receiving information, while another asserted it was those who lived near the road, those who returned from foreign employment, those with medium wealth and men who were most proactive in approaching JTAs. One JTA was more categorical: “Brahmin and Chhetri farmers are more receptive, indigenous groups are slower and the Dalits are the most disinterested.” These responses may reflect local prejudices, but they are in line with the long-established sociological literature on agricultural innovation which claims that it is the wealthier, more educated and higher status farmers who first adopt an innovation while poorer agriculturalists with smaller land holdings lag behind (Rogers, 1962). Given the fact that the programs themselves are insufficiently funded to reach all potential recipients, attention is rationed by the logic of convenience according to which persons that require the least outreach efforts receive services. Local inequalities are exacerbated as a result. For example, one JTA reported that the DADO allocated Nepalese Rupees 40,000 (~USD$370) for promoting beekeeping among unemployed youth, but many better-off farmers accessed this program instead.
As in the case of forest management, resource limitations generate conflict, which is again mediated with the help of local political parties. One JTA put the whole cycle quite succinctly:

Limited program is disbursed from the district level, while the demand from farmers is high. This causes conflict while distributing program to farmer. Mostly the problem is solved by taking help from local politicians.

Not surprisingly, the majority of villagers who do not receive services reported being dissatisfied with the DADO. Dissatisfaction was the highest among those who have received no services and not had any contact with JTAs, while satisfaction levels were higher among those who had received some benefits such as subsidized seeds. Queried about whether they believed DADO has sufficient resources to provide the full extent of services desired by the community, many respondents said they believe that it did while only a few recognized the staffing constraints and almost none recognized the financial limitations. Such low levels of satisfaction can call into question legitimacy of the state apparatus unless the true extent of resource limitation is broadly understood.

Given this state of affairs, the proposed policy initiative within the MoAD to explore and prioritize off-farm employment is one of several examples of efforts which cannot be supported with the resources on the ground. Indeed, in our interviews, none of the agricultural department officials said they had any knowledge about ministerial initiatives to promote off-farm employment, a policy initiative which is clearly stated in the NAPA. Similarly, other interventions suggested by the rural development literature for livelihood improvements such as greater emphasis on market deepening (rather than just improving local productivity which may often lead to production gluts) are impossible without increasing staffing and funding in decentralized public agriculture agencies. In the meantime, villagers respond that they are haphazardly adapting to climate change by switching to varieties which require less water and by increasing their use of pesticides and fungicides.

5. Discussion: the state and adaptation capabilities in Nepal
In this study, we focused on the effects of formal and informal rules and of organizational capacities on decision-making in communities and in the front lines of administrative agencies in Nepal. In our interviews with both community members and administrative staff, we asked detailed questions about climate change impacts and responses, and we found that overall both groups of actors possessed detailed knowledge about climate vulnerabilities. We also reviewed Nepal’s major climate policy documents, including NAPA, LAPA, Forest Sector Strategies, etc., and found them to be comprehensive and detailed. Indeed, many analysts (Ford et al., 2013) consider Nepal’s adaptation policies among the best in the world. Yet, despite this field level knowledge, comprehensive policies and the emergence of a growing epistemic community dedicated to responding to climate change, we found in our investigation of forests and agriculture in Nepal that implementation of climate adaptation strategies is superficial, uneven and inadequate.

In particular, we found institutional frameworks have been more successful in securing entitlements than in creating initiatives to address climate challenges by instigating social processes of livelihoods protection and transformation. Although still not ideal, representational safeguards in local level resource management and deliberative developmental spaces such as the CFUG ensure levels of resource distribution and transparency which are many degrees better than the situation which prevailed before these spaces were constructed. In contrast, deficiencies in developing adaptation and resilience
strategies based on livelihood improvements are severe. We trace these to administrative agencies that are as weak as the communities they must serve and interventions outside the administrative structures (i.e. by CSOs in donor-funded projects) that are sporadic and dispersed. At the same time, we found front line workers frustrated with the lack of resources for performing even the minimum of their assigned tasks.

Are the administrative staff in Nepal’s frontline agencies suitable to deal with these challenges or are they incapable and disinterested? Rutt and Lund (2014) studied forestry projects and found that donors preferred giving money to CSOs rather than governments because they believed “capacity must precede empowerment” because the image of LDCs administrations is one of incapability and disinterest. While they pointed to the dangers of leaving government out, they did not actually study the local governments themselves and relied on eliciting opinions from CSOs and donors, which is similar to what other researchers on the issue have also done. By studying in detail the administrative structures as well as the communities they serve, we are able to offer some triangulated observations on this issue and find that the Nepalese front line agency workers and local governments are neither incapable nor disinterested.

In the interviews, almost no staff reported policy or procedural barriers to taking initiative, although they did say there were no incentives other than self-satisfaction to doing so. In spite of this, several staff members were able to describe specific occasions when they acted on their own initiative indicating that frontline staff did see the ability to deliver services and solve community problems to be motivational factors notwithstanding the high levels of frustrations with working conditions. Moreover, they consistently expressed a desire for more (and frustration with current) equipment and training, which indicates that they do wish to receive validation from their work.

Intrinsic incentives for organizational performance – i.e. those which actors derive merely from involvement in an activity and not from external rewards – are emphasized as predictors of organizational success in the organizations literature based on psychology and behavioral economics. We find that these are not absent in Nepal. This is significant because behavioral research suggests that intrinsic incentives allow individual interests to align more naturally with organizational interests (Frey et al., 2013). This stands in juxtaposition to a principal-agent optic (which orthodox economists and donor agencies emphasize) that require expensive agency-based enforcement structures. Such structures have high fixed costs and therefore economies of scale, which make them appropriate for wealthier and larger economies but unaffordable in poorer and smaller ones. The takeaway from this is that LDCs like Nepal cannot be expected to have the kinds of regulatory apparatus that donor countries possess and expect and therefore more emphasis should be placed on the cultivation of intrinsic incentives.

Intrinsic incentives still require adequate manpower and capacity for creative organizational design of the kind vividly described by Tendler (1997) in the case of healthcare extension workers in Northeast Brazil – a case which was, in fact, predicated upon massive hiring of new staff. Basic resources are also important. Our field visits revealed that while the capillary structures of the state are present in the districts and villages, they are rudimentary and fragile. Almost no forest or agriculture offices exist beyond the district level and even at the district level the quantity and quality of the construction and equipment is a common cause for dissatisfaction among staff. Not infrequently, front line staff have to work out of what they called “briefcase offices”, that is they lack even a building to work in. In other cases, the offices themselves are in precarious conditions. One of the district forest service offices we visited even had a tree branch precariously holding up the roof. Many such offices collapsed in the 2014 earthquake.
Rather than disinterest, Nepal’s public administration suffers from a mismatch between expected responsibilities and available resources. Comparing the diffuse responsibility and broader claims to government programs with the focused and adequately funded (in terms of staff including expensive foreign experts, equipment and salaries) donor programs will no doubt result in impressions of poor performance in the former, especially among community members who are not in a position to understand the background of differential access to financial resources. This also explains incidence of and frequent complaints about the low uptake by local governments of development projects initiated by CSOs using donor funds.

Related to this, we find that performance and organizational goals included in the NAPA and associated plans (GoN, 2016b, 2014c, 2011a, 2011b) diverge too much from organizational resources and capabilities for them to be realistic. These goals are not trickling down to the field level even though the policies are comprehensive in their texts and the central government staff is well-versed in them. Not surprisingly, implementation of these plans and the functioning of the new climate change management organizations that they established are moribund. For example, the Climate Change Council – a body whose establishment was mandated by the NAPA with the responsibility for managing and coordinating various programs at the political level (it is supposed to be chaired by the Prime Minister and composed of the ministers of all the relevant ministries) and approving the annual Climate Change Fund expenditures – has a Web page which was last updated in 2012 and referred to the fact that the Council had met four times in 2010.

The tendency to overprescribe an agenda for LDC administrations – which derives from the structural realities of climate change adaptation management where policy texts are paid for by donors and written by consultants – comes with several attendant risks, including that of a deteriorating relationship between governments and donors. While it could be argued that identifying needed policy actions brings into sharp relief the capacity gap which exists and in doing so provides also a road map for capacity development (Willems and Baumert, 2003), our research and the empirical record over the past several years indicates that the capacity gap is too large and the required resources for filling this gap are still being negotiated, as a result of which policies such as the NAPAs are already becoming obsolete and, worse yet, more promising and realistic policy options are not being developed or implemented.

Instead, we found evidence from our interviews to suggest that a mismatch between capacities and expectations are stressing relations between community members and state structures. These constraints reinforce local-level asymmetries of power in access and in entitlements as work pressures leave the staff unable, even if willing, to resist maneuvering for privileged access to limited resources and programs. Because of this, low-level conflict has increased as different interests grapple for the few resources that do trickle down. Ambitious plans and policies as are generally written into most NAPAs create expectations and a failure to fulfill these or lack of expectations management erodes trust and legitimacy between a government and its citizens. This, in fact, may be one of the reasons that the impression of an unresponsive state.

Moreover, if targets are not calibrated to capabilities, then the persistent tendency towards failures engendered by the bridge-too-far syndrome erodes organizational and individual self-confidence and heightens passivity in the face of risks. Approaching the issue of targets from the perspective of organizational psychology, March and Shapira (1992) had theorized that risk-seeking behavior increases as the targets come into view. This insight helps explain the idleness of bureaucracies in LDCs. Risk taking is essential in the
process of finding and implementing solutions because the potential for error is inherent in trial and learning processes. Risk averseness in organizations and societies that derives from mistrust and resource constraints thus limits progress and increases passivity which, in the presence of imminent threats like global climate change, exposes the entity to even more danger.

6. Conclusions

The reliance of LDCs on donor financing for climate change adaptation has introduced several distortions which derive principally from:

- a lack of trust in the LDCs administrative structures and the consequent reliance on contracting CSOs to propose and manage discrete projects; and
- a mismatch between ambitious climate change adaptation policies written by consultants and on-the-ground capacities.

Bringing the government back in is a challenge and enabling administrative agencies to address climate change rests on a tripod of solutions to what is partly an organizational challenge, partly an institutional challenge and partly a policy-choice problem. The organizational challenge is to be able to create protocols and intrinsic incentives which empower and grant autonomy to front line workers, and to complement these with necessary rightsizing of line departments so that abilities match expectations. Moreover, given inevitable limitations on oversight capacity, more creative thought needs to be directed towards improving intrinsic incentives for the staff. The institutional challenge, given limited enforcement capabilities, is to reorient rules towards outcomes and search for solutions that stimulate intrinsic rewards rather than towards process validation rules which numbs them. Distribution of entitlements is important and we find the first generation of reform in community forestry and village councils has made substantial progress in these arenas. The second generation of reforms would need to build on this by emphasizing local institutional arrangements which induce risk sharing and development. Finally, the policy-choice challenge is to avoid the temptation to write aspirational policies which do not have clear and feasible strategies to obtain the resources necessary for proper policy implementation. The resulting policies may be less ambitious but more actionable and would allow much better leveraging of institutional and organizational capacities and potential that currently exist even as we wait for transformational developments in the field of climate change finance and management.

While the practice of public management in the developed countries stresses autonomy in public sector agencies based on neo-institutionalist and network theories – both of which extol autonomous agencies as necessary to cope with increasingly complex environments and emphasize the importance of performance incentives (Verhoest et al., 2004) – in LDCs the overwhelming preoccupation is with accountability. This is both delaying the transfer of resources to these units and deferring the construction of incentive structures which facilitate entrepreneurial thinking. Nurturing these abilities would require policymakers and policy enablers to encourage autonomous decision-making at the local level through incentives and structural arrangements which are designed to develop and build support for more entrepreneurial public sector attitudes in collaboration with local communities. At the very least, significant increases in local staffing and financing will be required to replace sporadic initiatives with larger scaled responses, in the absence of which increased outmigration is likely to remain the main adaptive reaction (Jha et al., 2017), at least for the younger and more educated.
Notes


2. In the end, we discovered that more important than altitude was the presence of road connectivity. Dolakha district, for example, which is in the high mountains, has a good road connection with Kathmandu, which enables goods and services to move more quickly and cheaply. Indeed, as the Swiss-financed road connected the district, it has grown rapidly to become a regional hub.

3. Some cash crops such as vegetables and spices do find space in local markets, but the levels of production are low. One notable exception was in the case of Dolakha district, where potato cultivation has been successful and is marketed as far as Kathmandu.

References


Further reading

Corresponding author
Sunil Tankha can be contacted at: suniltankha@gmail.com
Climate change and variability perceptions in Ga-Dikgale community in Limpopo Province, South Africa

Enerst Shingai Chikosi, Shingirai Stanley Mugambiwa, Happy Mathew Tirivangasi and Sejabaledi Agnes Rankoana

Department of Sociology and Anthropology, University of Limpopo, Sovenga, South Africa

Abstract

Purpose – Perceptions of climate change and its threats to rural communities are among major challenges faced by scientists around the world. A few studies prove that these communities are aware of change in climatic conditions and their impacts on people’s livelihoods. Climate change is usually perceived as increasing warming days, erratic rainfall patterns, ecological variability, biological change and their adverse effects on human beings. This study aims to assess Ga-Dikgale community’s perceptions on climate change and variability.

Design/methodology/approach – A qualitative research method was adopted and community members of age 60 and above in Ga-Dikgale community were purposively selected as participants in the study. Data were collected through in-depth interviews, and thematic content analysis was used to analyse data.

Findings – The study found that the community perceives climate change and climate variability based on changes in temperature patterns, erratic rainfall patterns, seasonal change, depletion of biodiversity, decline in subsistence crop production, change in water quality and cessation of cultural activities.

Originality/value – The study concludes that community’s perceptions of climate change are largely centred on variations in temperature and rainfall patterns. It has been established that knowledge of climate change in rural communities is of paramount importance in as far as adaptation to climate hazards is concerned.

Keywords Temperature, Climate change, Changes in rainfall patterns, Seasonal changes

Paper type Research paper

1. Introduction

This paper assesses climate change and vulnerability perceptions in the South African rural community of Ga-Dikgale. Perceptions of climate change and its threats to rural communities are among major challenges faced by scientists. Fewer studies prove that rural communities are aware of change in climatic conditions (IPCC, 2007). According to Bhusal (2009), local people share experiences of climatic conditions, ecosystem function and process
and biological systems. Climate change is perceived as increasing warming days, changes in rainfall patterns, ecological variability, biological change and their adverse effects on human beings. Other studies indicate that warm days are rapidly increasing, rainfall pattern is unpredictable, seasons are changing, incidents of drought are increasing, hailstorm occur abnormally and water resources are decreasing (Kruger and Shongwe, 2004; IPCC, 2007; Gurung and Bhandari, 2009).

The study explored the community’s perceptions of climate change. It demonstrates the community’s awareness of change in climatic conditions in the form of increased temperature and changes in rainfall patterns. Research on local communities’ explanations of climate change and their potential for adaptation to climate change hazards is limited, however. There is very little attention given to the rural communities in which livelihoods are mostly climate-dependent. There are assertions from fewer studies that climate change and its negative impacts are mostly felt by poor and rural communities whose livelihoods are dependent upon favourable climatic conditions (Bhusal, 2009; Chaudhary and Aryal, 2009; Mugambiwa, 2018).

1.1 Rural communities and climate change

Indigenous societies are largely excluded from climate change policies and decision-making processes as shown in a virtual lack of references to the existing traditional knowledge on climate change in the global, national and local climate change discussions. To date, valuable insights held by rural communities globally about direct and indirect impacts of climate change, as well as mitigation and adaptation approaches, remain largely unrecognised. Bhusal (2009) attests to this observation that stressful climatic extremes leave local communities searching for solutions to minimise climatic and social threats to their livelihood (Smith and Reynolds, 2005; Brohan et al., 2006; Caesar and Alexander, 2006). In local communities, community members have developed indigenous and culture-based mechanisms of coping with harsh weather conditions, which negatively affect their subsistence economies, cultural rituals and festivals, health conditions and the natural environment from which they derive their livelihood (IPCC, 2007; Jianchu et al., 2007; Mugambiwa, 2018).

Furthermore, it is reported that rural communities’ explanations of climate change are largely based on variations in temperature and rainfall patterns (Jianchu et al., 2007). Rural communities are aware that devastating changes in their living conditions such as malnutrition, poverty, water and air contamination, increased risks of disease, floods, soil erosion and depletion of biodiversity are as a result of climate and environmental variability. The increase in temperature has been a major concern for local farmers (IPCC, 2007). Observed change in rainfall and temperature patterns is supported by annotations of drastic increase in temperatures with negative impacts on the livelihood patterns of rural communities. These approaches to measure climate change are important in planning mitigation measures and to adapt to climate change (FAO, 2007).

The history of changing temperature in South Africa’s weather records over the past six decades indicate that the region’s climate is shifting. Analyses of change in climatic conditions in South Africa show that, the country’s average temperature is likely to increase by 1-3°C, with the interior experiencing the greatest increase (Kruger and Sekele, 2012). Nevertheless, there are assertions that climatic conditions are changing, and that these reflect trends elsewhere in the world (Mugambiwa and Tirivangasi, 2017). Observations of regional and seasonal variation in different parts of the country resulted in high rainfall regions, and seasons are recording increases in precipitation and becoming wetter, whereas low rainfall regions and seasons are recording decreases in precipitation and becoming drier.
The changed intensity and amount of rain positively correlate with the increase in water-induced disasters like floods. The water springs in the area have been drying up in the recent past (Gurung and Bhandari, 2009).

Kruger and Sekele (2012) attest that rural communities in Limpopo Province observe unusual phenomena such as fast maturity of maize, new types of pests, short stalk of rice and wheat. SAGUN (2009) believes that changes in temperature and rainfall are creating favourable environments for pests, diseases and invasive species to emerge, spread and encroach on agriculture and bushlands. Most people follow traditional cultivation practices that rely on seasonal rain water. Changes in rainfall patterns and hailstorm contributing to soil erosion, soil fertility loss and crop damage are having an adverse impact on livelihoods of most of these communities, thus increasing the risk to food security. Although drinking water is increasing because of availability of water storage tanks and water pipes, local people are facing more drought periods, resulting in decrease in natural springs and irrigation water. This may affect agriculture, and subsequently food security (Kruger and Sekele, 2012).

The Food and Agriculture Organisation [FAO] (2007) and Jianchu et al. (2007) reported that as climatic patterns change, habitats change and so do the spatial distribution of agro-ecological zones, distribution patterns of plant diseases and pests, which can have significant impacts on agriculture and food production. The forestry industry could probably tolerate a small increase in temperature, but a decrease in rainfall would reduce the area which supports plantations and the growth rate of the trees. A positive point is that rising carbon dioxide could help reduce water use by plantations. FAO (2007) predicted that in developing countries, 11 per cent of arable land would be affected by climate change, including a reduction of cereal production in up to 65 countries, about 16 per cent of agricultural gross domestic product (FAO, 2007). Changes in rainfall patterns, ecological variability and biological change have their adverse effects on human beings. There is observable increase in warm days, unpredictable rainfall, changing seasons, incidents of drought, hailstorm, wind and decreasing water sources, changes in flowering and fruiting time, invasion of new plant species and the reduction of some indigenous plants (Jianchu et al., 2007).

Fewer studies have addressed local community’s experiences and challenges resulting from changing climatic conditions (Sillitoe, 1996; Seager, 2008). This may be because of the fact that while recent research on local ecological knowledge is propelled by concerns about environmental conservation and intellectual property rights; knowledge about climate cannot be managed, transferred, appropriated; or consumed the same way as cultural or natural resources. The current study, therefore, seeks to provide local perceptions of climate change and variability with the use of Ga-Dikgale community as a case.

2. Description of the case study location

2.1 Study area

Figure 1 presents the geographical location of Ga-Dikgale community, which falls under Capricorn District Municipality. The area is located in Limpopo Province in South Africa, approximately 40 km from Polokwane City, the capital of Limpopo Province. The main ethnic group in the area is the Pedi Kone of Ga-Dikgale. Other Northern Sotho groups in the area include the Kgaga-Kone, Batlokwa, Kolobe, Hananwa, Babirwa, Nareng, Tlou, Pai, Phalaborwa and Hlaloga. The primary language in the area is Sepedi. The area is on the Highveld Plateau, which is bounded in the south and south-east by the Strydpoort Mountains and in the east and north-east by the Wolkberge. Soils found in this area are more related to the parent material, which is granite. Topography of the area is
Figure 1.
Geographical location of Ga-Dikgale

Location of Ga-Dikgale

Source: Authors
Topography of the area is characterised by irregular undulating lowlands with low-lying mountains. It also has some moderately undulating plains. The bushveld is made up of a combination of dense shrubby thickets and small trees of both acacia and broad-leaved species. Tall Mountain Aloes, *Aloe marlothii* are conspicuous and are characteristics of granite boulders and *koppies*, which give this habitat its unique appearance. These outcrops support a great variety of plant life including *Euphorbia Cooperi* and various Ficus, Combretum and Acacia species. The thickets consist mainly of *Acacia gerrardii*, *Dombeya rotundifolia*, *Cassonia natalensis*, *Pappea capensis* and several Euclea species. Many of these habitat types, however, have been lost because of deforestation and rural densification and they may be considered threatened (Limpopo Department of Finance and Economic Development [DFED], 2004).

Ga-Dikgale is a community of about 9,000 people and consists of 23 villages. According to the South Africa Community Survey (2011), Limpopo Province is accounted for approximately 5.2 million of the 48.5 million national population.

The site is peri-urban and most of its inhabitants belong to the Moria Zionist Church, which has a combination of Christian and traditional beliefs, while others belong to the Lutheran or Anglican churches. A large proportion of adults are migrant workers, some residing in the nearby mushrooming shopping complexes, while others work as farm labourers on neighbouring farms, or as domestic workers in nearby towns. Unemployment rate in the area is rather high (Stats SA, 2013).

The community is an impoverished rural settlement, made up of mixed formal and informal settlements, scattered around the periphery of the municipal boundary with improved services and infrastructure. Dwelling units consist of a mixture of shacks, traditional mud huts and conventional brick houses. Settlement patterns are conducive for development. Many examples of human ingenuity and creativity are evident, which have created the conditions for survival and enrichment (Alberts, 2008). There are four primary schools and three secondary schools in the study area. In all the schools, the classrooms are overcrowded and few educational amenities are available. The adult literacy rate is 79.8 and 73.6 per cent in males and females, respectively. A few households have water taps in their yards, but most residents fetch water from taps situated at strategic points in the villages. There are households that have pit latrines in their yards but there is no organised waste disposal (Stats SA, 2013).

The villages are electrified, but some of the residents cannot afford to pay for this service. A network of untarred roads connects these villages. The main road to the west of the area provides public transport to nearby Mankweng Township, where there is a government hospital and other urban facilities (Alberts, 2008). Provision of household services has increased between 2001 and 2011. The municipality has 46 health facilities in the form of hospitals and clinics, excluding private hospitals (Stats SA, 2011). One of the key social problems facing the Ga-Dikgale is poverty. Unemployment estimates in the Municipality vary between 45 and 70 per cent of the economically active population (people between the ages of 15 and 64 years). Establishing, improving and maintaining rural infrastructure in the form of water and power supplies, as well as reliable modes of transport will alleviate the burden on women and children who bear the brunt of inadequate infrastructure in the rural areas (Stats SA, 2011).

Fewer subsistence crops are grown around houses in the home gardens and ploughing fields. Agriculture has been identified as the main land use (more than 80 per cent) in the area. The agriculture sector contributes only 1.9 per cent to the local
economy and accounted for 9.4 per cent of employment opportunities in 2004. Privately owned farms account for the bulk of production in the local agricultural sector. Other forms of farming in the community include urban agriculture and subsistence farming (Department of Rural Development and Land Reform [DRDLR], 2009). The most common subsistence crops are maize, beans, melons and sweet reed. Cattle and sheep are raised by fewer households.

3. Methodology

3.1 Research design
A qualitative research method and an exploratory design were adopted for this study. The study was designed to understand the perceptions of climate change.

3.2 Population and sample
The study population constituted of community members either aged between fifty and above or those who had general knowledge of climate change. Ga-Dikgale community was chosen based on the fact that it is one of the numerous rural communities in South Africa that are severely affected by the effects of climate change. This is because the community largely depends on the natural environment, and crop production and the rearing of animals constitute the people’s means of survival. Hence, in the event of drought or excessive rainfall, as a result of climate change, their livelihoods are adversely affected. Purposive sampling technique was used to select the participants. This type of sampling technique ensured the exploration of the phenomena across genders to obtain experiences of climate change from male and female members of the community. An equal number of male and female participants was selected to take part in the study.

3.2.1 Sampling procedure. In this ethnographic research approach, the respondents were selected on the basis of their knowledge of the phenomenon being studied. For example, according to Cotton (1996), the respondents should have good, relevant knowledge of the domain of the study and should be able to interpret the meaning of their own cultural phenomena. Hence, before each interview, the respondents were asked if they had ever heard about climate change. If they had, the interview would continue and if they had not, the researcher would inquire about the other criterion which is their period of residence in the community.

3.3 Data collection
Data were collected through in-depth interviews and field observations. In-depth interviews help the researcher to achieve the same level of knowledge and understanding as the study respondents. The technique is generally used when detailed information is needed from individuals in the study population (Walter, 2006). Respondents frequently provided additional information regarding their knowledge of climate change. Interviews, which were tape-recorded, were conducted concurrently with observations. These were conducted in the households of the respondents and they were conducted in the local language (Sepedi) to encourage free disclosure. Transect walks were taken to the nearby bushes to view indicators of climate change as explained by the respondents.

A list of climate associated questions was developed in order to pose the same questions to all the respondents. Open-ended questions were put to the respondents, but they were also given the opportunity to discuss issues which they deemed relevant. Throughout the research process, the respondents were asked for further explanations

Climate change and variability perceptions
as new issues arose. The interview schedule commenced with biographical information of the respondents such as age, gender, educational level and marital status. These were followed by open-ended questions, which focussed on the respondents’ perceptions of climate change and its impact on the livelihood of the community. The interview guide comprised the following questions:

- **Q1.** What is your understanding and knowledge about temperature, seasons and rainfall?
- **Q2.** Are temperatures, seasons and rainfall patterns in your area the same as during the time when you/your parents/your grandparents were born?
- **Q3.** Are you noticing any change?
- **Q4.** What are the indicators of change in temperature, seasons and rainfall patterns?
- **Q5.** Are you noticing any change in the cultural activities as a result of change in temperature, seasons and rainfall patterns (as a result of climate change)?
- **Q6.** Which cultural activities are mostly affected?
- **Q7.** Are there seasonal rituals and celebrations affected by this change?

The time allocated for each interview was an average of 1 h and 30 min. Interviews were conducted in the households of the respondents where they were most comfortable and local language (*Sepedi*) was used to encourage them to speak and discuss the issues freely and easily.

### 3.4 Data analysis

The collected data were translated from *Sepedi* into English by a language expert and transcribed by the researchers. Thematic content analysis was employed to analyse data, which was organised into categories on the basis of themes, concepts or similar features. The researcher developed new concepts, formulated conceptual definitions and examined the relationship among concepts. Data from the field consisted of infinite number of possible answers and were carefully managed, read, compared, categorised and recorded. Furthermore, data were organised into different themes according to the study objectives.

### 4. Findings and discussion

This section presents the findings of the study and discussion thereof. The section begins with biographical information of the participants followed by their knowledge of climate change, changes in temperature, changes in rainfall patterns, depletion of biodiversity, decline in subsistence crop production, change in water quality and cessation of cultural activities. The findings were supported accordingly with the relevant existing literature.

Table I presents biographical information of the study participants. Collection of information about gender statistics was to determine the males’ and females’ knowledge of climate change. The rationale for capturing data about the age of the respondents was to find out which age group in the study area was more likely to possess knowledge about climate change and the adaptation measures to cope with the impact of climate change on their livelihoods. A larger percentage of the respondents (55 per cent) falls between the age group of 60 and 69 years. Only 8 per cent of the respondents were older than 80 years. This
shows that a large number of community members who participated in this study stayed in the community for more than fifty years. The reason for probing the educational qualifications of the respondents was to find out whether community members were able to read information given in the media about the impact of change in temperature, seasonal and rainfall patterns and how these affect socio-economic and health conditions. The researchers also wanted to establish whether community members were capable of participating in debates about climate related issues affecting their community.

4.1 Knowledge of climate change
The community understands climate change on the basis of change in temperature and rainfall patterns. The respondents observed that the summers were extremely hot while the winters were warm with little unusual precipitation. It is, however, important to mention that climate change in the study is explained as change in temperature and rainfall patterns. When asked about their understanding of climate change, most of the participants referred to drastic increase in temperature patterns traced back about 10 years. For instance, one respondent had the following to say:

My understanding of climate change is that there is a severe shift in weather conditions that we have gradually witnessed over the years. In the previous ten years or so the seasons have changed in that it is now extremely hot in summer and such high temperatures have dire effects on our crops and domestic animals. During the same period we have received little amounts of rainfall (Occupation: Farmer; Age: 60; Gender: Female: Moduane village).

It is reported that rural communities’ explanations of climate change are centred on variations in temperature and rainfall patterns manifest as rising temperature trends and scarce rainfall (IPCC, 2013). Rural communities are aware that devastating changes in their living conditions such as malnutrition, poverty, water and air contamination, increased risks of disease, floods, soil erosion and depletion of biodiversity are a result of climate and environmental variability (Gandure et al., 2013).

4.2 Changes in temperature and rain patterns
The study found that the community experiences change in climate with increasing change in temperature patterns such as hotter summers and warmer winters. Lack of rain, withering of plant materials, deaths of livestock and cessation of subsistence crop productions as the consequences of excessive heat has also been reported. One of the participants said the following:

<table>
<thead>
<tr>
<th>Table I.</th>
<th>Biographical information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
</tr>
<tr>
<td>34%</td>
<td>66%</td>
</tr>
<tr>
<td>Age</td>
<td>60-69 years</td>
</tr>
<tr>
<td>55%</td>
<td>37%</td>
</tr>
<tr>
<td>Employment</td>
<td>Farmer</td>
</tr>
<tr>
<td>20%</td>
<td>40%</td>
</tr>
<tr>
<td>Education</td>
<td>No formal education</td>
</tr>
<tr>
<td>36%</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors
The changes in climate is widely noticed through rapid increase in temperature patterns such as extremely hotter summer and warmer winters, severe changes between heat and cold in the same season. Also we have constantly received lack of sufficient rain which has resulted in withering of plant materials and the deaths of livestock (Occupation: Farmer; Age: 72; Gender: Female: Moduane village).

Correspondingly, Intergovernmental Panel on Climate Change [IPCC] (2007) asserts that remarkable changes in temperature patterns were reported between the years 1960 and 2009, where the mean annual temperature increased by at least 1.5 times the observed global average of 0.5°C over the past five decades. These variations are supported by observations and projections on climate alterations in the form of increased temperatures and changes in rainfall patterns by scientists worldwide. Increased temperature, drying up of soils, increased pest and diseases pressure, shifts in suitable areas for growing crops and livestock, floods, deforestation and erosion are the signs that climate change is happening and represents one of the greatest environmental, social and economic threats (IPCC, 2007).

Furthermore, temperature analysis for Limpopo Province provides a noticeable increase of 0.12°C per decade in the mean annual temperature for the 30 catchments, over the 50 year period (Kruger and Sekele, 2012). A non-uniform pattern of changes in temperature was evident across the different catchments; 13 per cent of the catchments showed negative trends while 87 per cent showed positive trends in their annual mean temperature. Moreover, 20 per cent of catchments showed negative trends, while 80 per cent of catchments showed positive trends in their diurnal temperature range. Seasonal trends showed variability in mean temperature increase of about 0.18°C per decade in winter and 0.09°C per decade in summer (Kruger and Shongwe, 2004). The overall consequences of temperature increase include greater water evaporation, plant stress, a decline in quality and availability of surface and ground water, overall drying, increased likelihood of fire conditions and unpredictability of weather events and seasonal conditions. Plants, in particular, cannot keep up with rapid climate change. Small, isolated plant populations could go extinct as a result. South Africa has about 10 per cent of all the plant species in the world, of which about half occur nowhere else on earth (Kruger and Sekele, 2012). Apart from the widely visible changes in temperature, the study discovered that rainfall patterns had also shifted.

4.3 Changes in rainfall patterns

There was a general perception of decrease in rainfall trends among the respondents. They observed that the last time they had good rain was about 35 years ago. Since that time, rain has become unpredictable. Recent winter rainfall is attributed to change in cooler winters and warmer summers. It was reported that the community used to receive the first rainfall in September, but in recent years the first rain falls between October and November marked by thunderstorm. Changes in rainfall patterns resulted in drought with debilitating effects such as decreased subsistence economy, depletion of biodiversity and water resources. It was also found that the incident of drought has been increasing and is linked with the untimely and unusual rainfall patterns over the past few years. One respondent articulated that:

Previously rivers flowed all year round but today when the rains stop, most of the rivers in the area dry up. Also, summer rainfall is becoming unpredictable. In old times, there would not be rain during the dry season, and in the rainy seasons we had rain, sufficient rain but those things have changed. These changes have disrupted growth cycles (Occupation: Farmer; Age: 69; Gender: Female: Maselaphaleng village).
Climate change in the study is explained as change in temperature and rainfall patterns. There are observations of drastic increase in temperature patterns traced back about ten years which are responsible for excessively hot and dry summer and warm winter. The last period of good rain in the community has been the past ten years and since that time rain is unpredictable.

4.4 Depletion of biodiversity
Ga-Dikgale is rocky with patches of infertile sandy soil. Cattle in the area are responsible for bush encroachment, thus reducing grass cover and subsequently leaving the area exposed to bush fire occurrences. This process leads to reduced biodiversity, which most villagers complain about in their area. The respondents are of the view that the indigenous trees together with wild animals are perceived as nuisances by farmers and are therefore usually removed. The respondents observed that there had been a rapid loss of vegetation because of drought; the species under-grow and wither. Most affected indigenous species are the sources of medicine, fuel and fodder, which are overharvested with little chance of regrowth as a result of excessive heat and rainfall scarcity, as articulated by one of the respondents (Occupation: Farmer; Age: 75; Gender: Male; Ntsima Village).

Respondents’ knowledge of climate change vis-à-vis depletion of biodiversity is consistent with the farmers’ knowledge of changing climatic conditions in the Sahelian region of West Africa where they point to shrinking water bodies, disappearing plants and crops and changing settlement patterns as evidence of reduced rainfall over the past three decades of the twentieth century (Tschakert and Dietrich, 2010). Further explanations of climate change are persistent rainfall hazards such as drought which result in loss of livestock, fallow fields and deteriorating water levels in the rivers and boreholes, soil erosion, dust and depletion of biodiversity. The IPCC (2007) point out that rural communities are aware that devastating changes in their living conditions such as malnutrition, poverty, water and air contamination, increased risks of disease, floods, soil erosion and depletion of biodiversity are as a result of climate and environmental variability.

4.5 Decline in subsistence crop production
A decline in the subsistence economy is a major observable change reported by the respondents. Unpredictable rainfall patterns led to a decline in crop and livestock production. In the previous 10 years, the community depended on rain-fed crops. Recently, the community produces crops from home gardens which last for one season. In view of these variations in precipitation patterns and changes in crop production, community members use kraal and poultry manure to fertilise the soil to improve production. Evidence of decline in subsistence economy is also reflected in the fallow fields, cessation of cultural rituals and festivals, brewing of traditional beer and communal labour. Cattle, goats and sheep are produced by fewer households, and production is dependent upon stock feed bought from local white farms.

Community members have opted to switching from raising cattle to sheep and goats as a result of drought. The latter have lower fodder demands and thus do not require lush pastures that would only be available with abundant rainfall. A clear decline in sources of livestock fodder in the form of grass, leaves, fruits and pods is attributed to a decrease in grazing land because of new settlement patterns, changes in rainfall patterns, drought and changing weather conditions. One respondent asserted that:

Because of unpredictable rainfall patterns, crop and livestock production has greatly declined. In the previous ten or so years, the community depended on rain-fed crops but now the community
produces crops from home gardens which last for at least one season (Occupation: Farmer; Age: 68; Gender: Female: Ga-Tjale).

Based on the narratives of the respondents, rural communities are aware that devastating changes in their living conditions such as malnutrition, poverty, water and air contamination, increased risks of disease, floods, soil erosion and depletion of biodiversity are as a result of climate and environmental variability (Gandure et al., 2012). Rural communities’ explanations of climate change are centred on variations in temperature and rainfall patterns manifest as rising temperature trends and scarce rainfall (IPCC, 2013).

4.6 Change in water quality
Most of the respondents noticed that stream flows have dramatically changed in recent years, making it more challenging for livestock rearing. Drinking water supply is maintained through water storage tanks and the municipal water supply system. Although there is a clear consensus among the respondents that there is water shortages because of inconsistent running water, water conservation practices are not clear. For example, community members with storage tanks for water storage drain off the water from these and pour fresh water into them. Why? The water supply system faces major challenges in terms of operations of reservoirs and maintenance of facilities such as pumps and pipes. Commenting on this issue, one respondent pointed out that:

It is apparent that stream flows have dramatically changed in recent years and it has since become increasingly challenging to rear livestock. We also experience severe water shortages due to inconsistent running water. Even though there are facilities in place to provide us with water, the system faces major challenges in terms of operations of reservoirs and maintenance of pumps and pipes among other things (Occupation: Retired; Age: 70; Gender: Female: Sefatong Village).

The shifts presented by the respondents ignite a situation in which water resources are less dependable, with significant social and economic ramifications. In addition to the runoff and spilt water that creates water-logged conditions around the communal taps the drainage problem worsens because of the lack of proper washing areas near the communal taps that have adequate drainage. It is evident that some community members have to travel to fetch water from communal water pumps where the distance is not within the rural development plan standards. Rainfall and precipitation over the country will also change. Summer rainfall is likely to be delayed. Temperature inversions are likely to become more severe, resulting in increased pollution issues. These effects will negatively impact the country and its citizens (Muhlenbruch-Tegen, 1992; Karl, 1993; Jones, 1994; Kruger and Shongwe, 2004; Kruger and Sekele, 2012).

4.7 Cessation of cultural activities
There were observations that cultural activities such as traditional beer-brewing, communal labour, division of labour and cultural dances have ceased to exist as a result of unpredictable rainfall. These activities are dependent upon subsistence crop production, which has been characterised by low produce as a result of unpredictable rainfall since the year 2006. In total, 80 per cent of the respondents indicated that there were changes in the livelihood patterns such as gathering and making crafts for festivals, rituals and income generation. In the off-season, diversified activities provide a way to use labour and other resources to earn income. One respondent asserted that:

I can ascertain that numerous cultural activities such as traditional beer-brewing, communal labour and cultural dances have ceased to exist. This is largely because of unpredictable rainfall.
These activities rely on subsistence crop production, which since 2006 has been characterised by low production as a result of unpredictable rainfall (Occupation: Unemployed; Age: 70; Gender: Female; Sefatong Village).

Fewer respondents showed that payment of lobola (bride price) used to be in the form of cattle, but recently cattle are replaced by cash payment. Collection of roofing grass, firewood, timber and river reed have also ceased to exist. Huts are retained by fewer households. Maintenance of huts is a challenge as the beams, walls and floors have to be maintained by using cow-dung and fresh timber. Cessation of these livelihood patterns is a major challenge to sustainability of cultural values of Ga-Dikgale community members. Elderly respondents considered rainfall as a supernatural gift and there were popular cultural rituals performed to request for rain from ancestral spirits. However, it was reported that these practices have gradually disappeared as people have lost faith in such rituals; they understand rain scarcity as a problem caused by the changes in climatic change. Rankoana (2016) attests to the fact that climate change is explained in terms of cessation of cultural activities and important livelihood patterns. These include consumption of traditional fruits and vegetables, brewing of traditional beer, production of traditional crops and livestock, celebration of the first-fruit rituals, communal labour and hunting and fishing. It was mentioned that rain-induced diseases such as cholera, bilharzia and dysentery are becoming common in the community as a result of use of contaminated water, drought and excessive heat. Also, a study by Mugambiwa (2018) on climate change indigenous adaptation measures used by a Zimbabwean community demonstrate that cessation of cultural activities is a critical issue. The study emphasises on the vanishing of numerous cultural activities because of inconsistencies in rainfall patterns and other changes in weather conditions. For instance, celebrations of first rains and fruits are no longer practised because of the shifts experienced in weather conditions which consequently affect farming activities. Correspondingly, Corlew (2012) studied the cultural impacts of climate change in Tuvalu and discovered that the community’s culture, history and traditions were affected by the changes and shifts in weather conditions. Hence, cessation of cultural activities is a serious issue that results from climate change in many communities around the world.

5. Conclusion
In conclusion, the study has established that Ga-Dikgale community members have a fair understanding of climate change. Also, community members are aware of the devastating changes in their living conditions such as poverty, water and air contamination, floods, soil erosion and depletion of biodiversity, which make them easily understand the changes occurring in weather conditions. The increase in temperature has been a major concern for the community; hence, knowledge of climate change in rural communities such as Ga-Dikgale is of paramount importance in as far as adaptation to climate hazards is concerned. This is because communities can only craft adaptation strategies for the climatic hazards that they are aware of.

References


Further reading


Corresponding author

Shingirai Stanley Mugambiwa can be contacted at: mugambiwashingirai@gmail.com

For instructions on how to order reprints of this article, please visit our website: www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: permissions@emeraldinsight.com
Analysis of influencing factors of Chinese provincial carbon emissions based on projection pursuit model and Markov transfer matrix

Lei Wen and Linlin Huang
Department of Economics and Management,
North China Electric Power University Baoding Campus, Baoding, China

Abstract
Purpose – Climate change has aroused widespread concern around the world, which is one of the most complex challenges encountered by human beings. The underlying cause of climate change is the increase of carbon emissions. To reduce carbon emissions, the analysis of the factors affecting this type of emission is of practical significance.

Design/methodology/approach – This paper identified five factors affecting carbon emissions using the logarithmic mean Divisia index (LMDI) decomposition model (e.g. per capita carbon emissions, industrial structure, energy intensity, energy structure and per capita GDP). Besides, based on the projection pursuit method, this paper obtained the optimal projection directions of five influencing factors in 30 provinces (except for Tibet). Based on the data from 2000 to 2014, the authors predicted the optimal projection directions in the next six years under the Markov transfer matrix.

Findings – The results indicated that per capita GDP was the critical factor for reducing carbon emissions. The industrial structure and population intensified carbon emissions. The energy structure had seldom impacted on carbon emissions. The energy intensity obviously inhibited carbon emissions. The best optimal projection direction of each index in the next six years remained stable. Finally, this paper proposed the policy implications.

Originality/value – This paper provides an insight into the current state and the future changes in carbon emissions.

Keywords Carbon emissions, Influencing factors, LMDI, Markov transfer matrix, Projection pursuit model

Paper type Research paper

1. Introduction
Climate change has aroused widespread concern around the world, which poses one of the greatest challenges to human beings. Greenhouse gas emissions are not considered as simple environmental affairs but involve some fields associated with the political and economic interests. These even impact the survival, development and security of one...
country (Yao and Qin, 2012). China now undergoes the rapid growth of urbanization and industrialization (Tan, 2012). There will still be the vast pressure on energy saving and emission reduction in China due to the large population, rapid development and increasingly prominent contradictions between resources and environment. Accordingly, how to promote energy savings and reduce carbon emissions in China have become a focus. In recent years, carbon emissions have been broadly studied and researched.

Kapusuzoglu (2014) studied the impact of GDP on CO$_2$ emissions. He suggests that nearly 4 per cent of the world’s future changes in CO$_2$ emissions are attributed to the changes in GDP with population density as an endogenous variable. Borhan and Ahmed (2012) built a simultaneous equation and assessed the relationship between the air pollution index and economic growth between 1996 and 2006 in Malaysia. Air pollution indicators consist of carbon monoxide (CO), sulfur dioxide (SO$_2$), nitrogen dioxide (NO$_2$), ozone (O$_3$), as well as particulate matter (PM$_{10}$). As these results suggest, the primary source of pollution in Malaysia originated from transport. From 1965 to 2010, GDP exports, energy consumption and CO$_2$ emissions in Thailand showed a two-way causal relationship. As the results suggest, energy consumption, exports or GDP resulted in CO$_2$ emissions (Anatasia, 2015).

Using co-integration and vector error correction models, Istaiteyeh (2016) found that per capita GDP consequently increased per capita electricity consumption. Katircioglu (2017) investigated the impact of oil price trends on CO$_2$ emissions in the traditional environmental Kuznets curve of Turkey’s economy. As the results suggest, the rapid changes of oil prices negatively impacted carbon emissions. Kalayci and Koksal (2015) analyzed the impacts of China’s air freight industry on CO$_2$ emissions from 1980 to 2011 using econometric models. Using the co-integration and vector error-correction modeling techniques, Ang (2007) examined the dynamic causal relationships between pollutant emissions, energy consumption and output for France. The results suggest that economic growth had a causal impact on the increase in energy use and pollution in the long run.

The logarithmic mean Divisia index (LMDI) method is used to decompose the factors affecting carbon emissions at the multi-regional level, which was verified by Ang et al. (2009). By using the LMDI method, carbon emission factors were decomposed into energy intensity, per capita GDP, energy consumption and population. The impact of these factors on carbon emissions was discussed (Vinuya et al., 2010; Wang, 2012). The impact of energy intensity, energy structure and output proportion on carbon emissions was analyzed by Xu et al. (2016). The carbon intensity factors in China’s industrial sector was decomposed as energy intensity, emission coefficient and structure. As the results suggest, energy intensity was the critical factor for inhibiting carbon emissions. Carbon intensity was improved by the emission coefficient, while the structure effect did not significantly impact carbon intensity (Liu et al., 2015). The drivers of carbon emissions were decomposed into industrial structure, energy intensity, etc. using the LMDI method, and the impact of these factors on carbon emissions in Beijing were explored (Wu et al., 2014).

Using the fuzzy clustering algorithm, Xia et al. (2011) investigated an integrative assessment on the Chinese industry from 2002 to 2007, classified the industrial sectors into five types and summarized the major characteristics of each type. Industries in Tianjin fell into four types, and the features of “emission-efficiency” were analyzed by conducting cluster analysis (Shao et al., 2014). Yue and Zhu (2010) divided the carbon emission types of 30 provinces, except for Tibet, into four regions in accordance with two indicators (i.e. the emission and discharge efficiency) using the cluster analysis method. Based on a projection pursuit model, carbon emissions in China from 1996 to 2008 were studied (Yao and Qin, 2012). Based on the accelerated genetic algorithm and projection pursuit method, Zhang (2016) conducted cluster analysis of carbon emissions in each province in China, obtained
the optimal projection direction that determined the degree of all factors and classified all regions in China into four types.

In recent years, the Markov prediction model has been used to predict the energy structure, as well as carbon emissions. Niu et al. (2012) came up with a method to calculate the transfer matrix, which was verified by the statistical data of energy consumption structure in a region. The research status and existing problems of carbon emissions in Jiangsu Province were analyzed by Zhu et al. (2015), and the Grey Markov prediction model was used to forecast carbon emissions from 2014 to 2020 in line with the data from 2002 to 2013. As the results suggest, carbon emissions in Jiangsu Province would reach nearly 334 million tons in 2020, and there would have been a rapid growth in carbon emissions in 2020. Huang and Shang (2015) built the traditional Grey Markov prediction model and improved the actual error of the initial prediction of the Grey Markov prediction. The improved new model was adopted to calculate carbon emissions in China. As the results suggest, the new model had higher accuracy and effectiveness in comparison with the traditional Grey Markov model.

In contrast to the wealth of studies primarily exploring the factors affecting carbon emissions in China, the contribution of each factor influencing carbon emissions and the prediction of these factors have been rarely discussed. To fill these gaps, we decomposed the factors affecting carbon emissions into per capita carbon emissions, industrial structure, energy intensity, energy structure and per capita GDP using the LMDI model, and the contributions of the five influencing factors to carbon emissions from 2001 to 2014 were studied based on the data of 2000. In line with the study of Shao et al. (2014), this paper chose 2000 year as the base year. Using the projection pursuit model, this paper investigated the optimal projection direction of each indicator from 2000 to 2014. The optimal projection direction can be well expressed as the influence degree of factor. Using the Markov transfer matrix, we predicted the weights of the five indexes in the next six years. By comparing the optimal projection direction and investigating carbon reduction ability and potential, this paper proposed the corresponding policy measures and suggestions.

2. Methodology
2.1 Carbon emission calculation method
In accordance with China’s central types of energy consumption, this paper primarily studied eight types of energy (i.e. coal, coke, crude, gasoline, kerosene, diesel, fuel oil and natural gas). There are some limitations that standard coal consumption was obtained by multiplying the energy consumption based on the standard coal coefficient. Thus, this paper calculated the standard coal consumption based on the average net calorific values of all energy and the CO$_2$ emission factor. Given this, carbon emissions may be calculated as:

\[ C = \sum_i E_i \times Q_i \times EF_i \times \frac{12}{44} \]  

where, \( i \) denotes the type of energy consumed; \( C \) is the total carbon emissions; \( E_i \) is the total consumption of energy \( i \); \( Q_i \) is the average net calorific value of energy \( i \); and \( EF_i \) is the CO$_2$ emission factor.

2.2 Decomposition analysis
Using the LMDI method, this paper subdivided the change of carbon emissions in China into five factors (i.e. per capita carbon emissions, industrial structure, energy intensity, energy
structure and per capita GDP) and analyzed the contribution and the rate of various factors to carbon emissions:

\[ C = \sum_i \frac{C_i}{E_i} \times \frac{E_i}{E} \times \frac{Y}{Y} \times \frac{P}{P} = \sum_i F_i S_i I_i R P \]  

(2-2)

\[ \frac{C}{P} = A = \sum_i F_i S_i I_i R \]  

(2-3)

where, \( C_i \) denotes carbon emissions of energy \( i \); \( E_i \) is the consumption of energy \( i \); \( E \) is the total energy consumption; \( Y \) is GDP; \( P \) is the population; \( \frac{C}{P} \) is per capita carbon emissions; \( F_i = \frac{C_i}{E_i} \) is the carbon emissions intensity, i.e. the consumption of carbon per unit of energy \( i \), which can be considered as a constant; \( S_i = \frac{E_i}{E} \) is the energy structure; and \( I = \frac{E}{Y} \) is the energy intensity, which was defined as the energy consumption of per unit of GDP. Because energy intensity is closely associated with the industrial structure, the impact of energy intensity on carbon emissions was measured by the industrial structure and energy intensity; \( R = \frac{Y}{P} \) is per capita GDP representing the degree of economic development.

The change in carbon emissions from the base year to year \( T \) can be calculated as:

\[ \Delta C = C^T - C^0 = \Delta F + \Delta S + \Delta I + \Delta R + \Delta P \]  

(2-4)

where, \( \Delta F, \Delta S, \Delta I, \Delta R, \Delta P \) are the contributions of carbon intensity, energy structure, energy intensity and industrial structure, per capita GDP and population, respectively. The decomposition equations may be calculated as follows:

\[ \Delta F = \sum_i L(C^T, C^0) \ln \left( \frac{F_i^T}{F_i^0} \right) \]  

(2-5)

\[ \Delta S = \sum_i L(C^T, C^0) \ln \left( \frac{S_i^T}{S_i^0} \right) \]  

(2-6)

\[ \Delta I = \sum_i L(C^T, C^0) \ln \left( \frac{I_i^T}{I_i^0} \right) \]  

(2-7)

\[ \Delta R = \sum_i L(C^T, C^0) \ln \left( \frac{R_i^T}{R_i^0} \right) \]  

(2-8)

\[ \Delta P = \sum_i L(C^T, C^0) \ln \left( \frac{P_i^T}{P_i^0} \right) \]  

(2-9)

where:

\[ L(C^T, C^0) = \begin{cases} 
\left( C_i^T - C_i^0 \right) / \left( \ln C_i^T - \ln C_i^0 \right) & C_i^T \neq C_i^0 \\
C_i^T & C_i^T = C_i^0 \\
0 & C_i^T = C_i^0 = 0 
\end{cases} \]  

(2-10)
And, the contribution rates of various factors may be calculated as follows:

\[ r_F = \frac{\Delta F}{\Delta C} \times 100\% , \quad r_S = \frac{\Delta S}{\Delta C} \times 100\% , \quad r_I = \frac{\Delta I}{\Delta C} \times 100\% , \quad r_R = \frac{\Delta R}{\Delta C} \times 100\% , \quad r_P = \frac{\Delta P}{\Delta C} \times 100\% \]

where \( r_F, r_S, r_I, r_R, r_P \) are the contribution rate of carbon intensity, energy structure, energy intensity and industrial structure, per capita GDP and population, respectively.

2.3 Projection pursuit

The projection pursuit model, proposed by Kruskal (1969), is a multi-data processing method projecting high-dimensional data into low-dimensional space under numerical optimization calculation, to find out the optimal projection reflecting the data structure characteristics. The model has no special requirements of data, and sample size can ignore the effects of variables not associated with the structure and features of the data, and can efficiently solve various practical problems (Kruskal, 1969). The specific steps are as follows:

- **Step 1**: Normalize the evaluation index. The normalization process is capable of eliminating the dimension of the index and unifying the range of the evaluation index.

  Normalize the forward indicator as:

  \[ x_{(i,j)} = \frac{x^{*}_{(i,j)} - x_{\min(j)}}{x_{\max(j)} - x_{\min(j)}} \] (2-11)

  Normalize the negative indicator as:

  \[ x_{(i,j)} = \frac{x_{\max(i,j)} - x^{*}_{(i,j)}}{x_{\max(j)} - x_{\min(j)}} \] (2-12)

  where, \( \{x^{*}_{(i,j)}|i = 1, 2 \ldots n, j = 1, 2 \ldots p\} \), the sample set of each evaluation index, is the index \( j \) of sample \( i \); \( n \) and \( p \) refer to the sample size and the number of indicators, respectively; \( x_{\max(j)} \) and \( x_{\min(j)} \) are the maximum and minimum values of the index \( j \), respectively; \( f \); \( x_{(i,j)} \) is the normalized sequence of indicators.

- **Step 2**: Construct a projection function \( Q(a) \). The \( p \)-dimensional data, \( \{x^{*}_{(i,j)}|i = 1, 2 \ldots n, j = 1, 2 \ldots p\} \), is incorporated into \( Z_{(i)} \), one-dimensional projection value with the projection direction \( a = \{a_{(1)}, a_{(2)}, \ldots a_{(p)}\} \), the unit vector in the projection pursuit method.

  Where:

  \[ Z_{(i)} = \sum_{j=1}^{p} a_{(j)} x_{(i,j)}, i = 1, 2, \ldots, n \] (2-13)

  When \( Z_{(i)} \) is incorporated, the distribution of the projection value is as follows: the local projection point is as dense as possible; it is better to gather into several points; the whole projection point is scattered as much as possible. Accordingly, the projection function may be expressed as:
\[ Q_{(a)} = S_z D_z \]  \hspace{1cm} (2-14)

where:

\[ S_z = \sqrt{\frac{\sum_{i=1}^{n} (Z_{(i)} - E_z)^2}{n - 1}} \]  \hspace{1cm} (2-15)

\[ D_z = \sum_{i=1}^{n} \sum_{j=1}^{n} (R - r_{(i,j)}) \cdot u(R - r_{(i,j)}) \]  \hspace{1cm} (2-16)

where:

\[ r_{(i,j)} = |Z_{(i)} - Z_{(j)}| \]  \hspace{1cm} (2-17)

\[ u_{(t)} = \begin{cases} 1 & t \geq 0 \\ 0 & t < 0 \end{cases} \]  \hspace{1cm} (2-18)

Here, \( S_z \) denotes the standard deviation of \( Z_{(i)} \); \( D_z \) is the local density of \( Z_{(i)} \); \( E_z \) is the average of the sequence; \( R \) is the window radius of \( D_z \); \( r_{(i,j)} \) is the distance between the samples; \( u_{(t)} \) is the unit step function.

- **Step 3**: Optimize the projection index function. When the sample set of each index is gained, the projection function varies only with the projection direction. Thus, the optimal projection direction may be calculated by solving the maximum problem of the projection function as follows:

\[ \text{Max: } Q_{(a)} = S_z D_z \]

\[ \text{s.t. } \sum_{j=1}^{p} a^2_{(j)} = 1 \]  \hspace{1cm} (2-19)

### 2.4 Markov transition matrix

The Markov transfer matrix, proposed by Russian mathematicians A. A. Markov at the beginning of the twentieth century, is a useful tool to predict the status of the future (Rabiner, 1990). By exploring the initial probabilities of different states and transition probabilities between states, it considers the time series as a stochastic process and determines the trend of the state change to predict the future (He, 2011). Specific steps are as follows:

- **Step 1**: Input experimental data and processing the data. A Markov chain with a set of states \( \{s_1, s_2, \ldots s_n\} \) and the transfer matrix \( A = (a_{ij})_{n \times n} \), where, \( a_{ij} \geq 0 \). The index \( j \) in \( t \) year is valued as \( y_{t}(j), j = 1, 2 \ldots k; t = 1, 2, 3 \ldots n \); the index \( j \) in \( t + 1 \) year is valued as \( y_{t+1}(j), j = 1, 2 \ldots k; t = 1, 2, 3 \ldots n \), where, \( \sum_{j=1}^{k} a_{ij} = 1, i = 1, 2, \ldots n \).

- **Step 2**: Determine the Markov transfer matrix using the least squares method. According to the properties of Markov chain, \( y_{t+1}(j) = \sum_{t=1}^{n} y_{t}(i)a_{ij}, (j = 1, 2, \ldots k) \) can be yielded. And, the transfer matrix \( A \) is yielded by solving the equation using the least squares method.

- **Step 3**: Predict the future state according to the Markov transfer matrix.
2.5 Data resources

The data for eight types of fuels in each province studied in this paper were collected from the *China Statistic Yearbook* and *China Energy Statistical Yearbook* from 2000 to 2014 (e.g. coal, coke, crude, gasoline, kerosene, diesel, fuel oil and natural gas). The carbon emissions were calculated by energy consumption, average net calorific value of energy and CO$_2$ emission factor, where the average net calorific of energy, and the CO$_2$ emission factor originated from the IPCC Guidelines for National Greenhouse Gas Inventories (2006). This paper selected five factors as influencing factors (i.e. per capita carbon emissions, energy intensity, industrial structure, energy structure and per capita GDP). Per capita carbon emissions were acquired by the total carbon emissions of each province divided by the total population of each province, in which the whole carbon emissions were gained by adding the carbon emissions of all types of energy, and the total population originated from *National Bureau of Statistics of China*. Because energy consumption is dominated by coal in various provinces, energy structure was acquired by the proportion of coal consumption to total consumption. Energy intensity was obtained by energy consumption divided by GDP, where GDP of each province came from *National Bureau of Statistics of China*. The industrial structure was obtained by sharing the added value of the secondary industry in the gross product, in which the added value of the secondary industry and the gross product originated from *National Bureau of Statistics of China*. Per capita GDP was acquired by GDP divided by the total population.

3. Results and discussion

3.1 Decomposition of carbon emissions factors

In total, 30 provinces in China were explored using the LMDI method. The contributions and rates of factors to the increase of carbon emissions in China are listed in Table I. The contribution values on carbon emissions of the provinces in China about five factors from 2000 to 2014 are listed in Table II. To more clearly compare the contribute values of the provinces, Table II was converted into Figures 1 to 5. The impact of five indicators was analyzed.

Table I suggests that, in the last 15 years, per capita GDP had the largest contribution to carbon emissions, taking up 67.42 per cent. The contribution of per capita GDP to carbon emissions had always been positive, showing an increase, and the growth was still fast in 2005. Due to the new normal of China’s economy, the national economic slowdown policy, per capita GDP growth has been slowed down since 2011. The economic growth could directly affect carbon emissions. With the decline of per capita GDP growth, the total carbon emissions would decrease accordingly. Accordingly, new normal of China’s economy contributes to carbon control.

Per capita GDP in all provinces is positive, as shown in Figure 1, suggesting that economic development accelerates the rise of carbon emissions in China. The contributions of per capita GDP in Hebei, Shanxi, Shandong, Inner Mongolia and Liaoning to national carbon emissions reached $18.19 \times 10^8$ t, $20.21 \times 10^8$ t, $22.26 \times 10^8$ t, $15.79 \times 10^8$ t and $16.79 \times 10^8$ t, taking up 7.03, 7.81, 8.60, 6.10 and 6.49 per cent, respectively. The industrial structure of these provinces is a typical energy-intensive structure. Chemistry, energy and steel industry are the economic foundation of these provinces.

The contributions of per capita GDP on Beijing, Ningxia and Hainan were just $3.58 \times 10^8$ t, $2.68 \times 10^8$ t, $0.58 \times 10^8$ t, taking up 1.39, 1.04 and 0.22 per cent, respectively. In Beijing, high-tech industries take up a relatively big proportion in industrial structure. Ningxia was a big agricultural province. In Hainan, tourism was the primary industry, and its
<table>
<thead>
<tr>
<th>Years</th>
<th>Industrial structure</th>
<th>Energy structure</th>
<th>Energy intensity</th>
<th>Per capita GDP</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value ($10^4$)</td>
<td>Rate (%)</td>
<td>Value ($10^4$)</td>
<td>Rate (%)</td>
<td>Value ($10^4$)</td>
</tr>
<tr>
<td>2001</td>
<td>-0.07</td>
<td>-4.04</td>
<td>-0.0039</td>
<td>-0.21</td>
<td>-0.67</td>
</tr>
<tr>
<td>2002</td>
<td>-0.06</td>
<td>-1.59</td>
<td>0.0458</td>
<td>1.27</td>
<td>-0.99</td>
</tr>
<tr>
<td>2003</td>
<td>0.43</td>
<td>6.62</td>
<td>0.21</td>
<td>3.21</td>
<td>-1.13</td>
</tr>
<tr>
<td>2004</td>
<td>0.80</td>
<td>7.61</td>
<td>0.11</td>
<td>1.03</td>
<td>-1.72</td>
</tr>
<tr>
<td>2005</td>
<td>1.35</td>
<td>4.37</td>
<td>0.19</td>
<td>0.62</td>
<td>-2.17</td>
</tr>
<tr>
<td>2006</td>
<td>1.81</td>
<td>9.05</td>
<td>0.26</td>
<td>1.32</td>
<td>-3.29</td>
</tr>
<tr>
<td>2007</td>
<td>1.93</td>
<td>7.37</td>
<td>0.34</td>
<td>1.32</td>
<td>-5.21</td>
</tr>
<tr>
<td>2008</td>
<td>2.25</td>
<td>6.84</td>
<td>0.33</td>
<td>1.02</td>
<td>-7.81</td>
</tr>
<tr>
<td>2009</td>
<td>1.92</td>
<td>5.41</td>
<td>0.13</td>
<td>0.38</td>
<td>-8.63</td>
</tr>
<tr>
<td>2010</td>
<td>2.57</td>
<td>5.92</td>
<td>-0.04</td>
<td>-0.10</td>
<td>-10.95</td>
</tr>
<tr>
<td>2011</td>
<td>2.91</td>
<td>5.57</td>
<td>0.22</td>
<td>0.43</td>
<td>-13.46</td>
</tr>
<tr>
<td>2012</td>
<td>2.49</td>
<td>4.44</td>
<td>-0.01</td>
<td>-0.02</td>
<td>-15.27</td>
</tr>
<tr>
<td>2013</td>
<td>1.67</td>
<td>2.84</td>
<td>-0.12</td>
<td>-0.21</td>
<td>-17.09</td>
</tr>
<tr>
<td>2014</td>
<td>1.23</td>
<td>1.99</td>
<td>-0.42</td>
<td>-0.68</td>
<td>-18.44</td>
</tr>
<tr>
<td>total</td>
<td>21.22</td>
<td>4.84</td>
<td>1.25</td>
<td>0.28</td>
<td>-106.83</td>
</tr>
</tbody>
</table>

**Provinces**

**Table II.** Contribution values and rate of carbon emissions factors for the provinces in China about five factors from 2000 to 2014.
development was driving the growth of the economy. Energy consumption in these provinces was small.

Energy intensity improvements efficiently alleviated the increasing of carbon emissions, as shown in Table I. From 2000 to 2014, the total of contribution value of energy intensity to carbon emissions change was $-106.825 \times 10^8$ t, with the average contribution ratio of 24.35 per cent. The contribution of the energy intensity to carbon emissions had always been
negative, and the degree of that was getting bigger and bigger, suggesting that active control of energy intensity would inhibit carbon emissions.

As suggested in Table II and Figure 2, from 2000 to 2014, only the energy intensity effect value of Hainan province was positive, i.e. $0.11 \times 10^8 \text{t}$, taking up 0.11 per cent. The energy intensity in Hainan province promoted carbon emissions.
Besides, the energy intensity effect values of other provinces were negative. In Hebei, Shanxi, Liaoning, Jiangsu, Henan and Guangdong, the degree of inhibition was relatively large as \(-5.44 \times 10^8 t, -9.02 \times 10^8 t, -8.79 \times 10^8 t, -6.24 \times 10^8 t, -4.36 \times 10^8 t, -6.32 \times 10^8 t\), respectively. These areas were energy-intensive regions. Improving energy efficiency would alleviate the increase of carbon emissions in China.

In Beijing, Jilin, Fujian, Jiangxi, Guangxi, Yunnan, Qinghai, Ningxia and Xinjiang, the degree of inhibition was small as \(-3.82 \times 10^8 t, -3.28 \times 10^8 t, -0.69 \times 10^8 t, -1.97 \times 10^8 t, -1.09 \times 10^8 t, -0.41 \times 10^8 t, -0.48 \times 10^8 t, -0.07 \times 10^8 t, -1.94 \times 10^8 t\), respectively. These areas were non-energy-intensive regions. Agriculture, high-tech industries and tourism were the focus of development. Energy intensity had less effect on carbon emissions. These areas had reduced the investment in primary energy consumption, and the energy structure had been reasonably improved and adjusted.

Table I shows that changes in the industrial structure around contributed to \(21.22 \times 10^8 t\), taking up 4.84 per cent, which caused the cumulative increase in carbon emissions. The contribution of the industrial structure to carbon emissions was changed from being negative to positive in 2003. From 2003 to 2010, the contribution rate of industrial structure for several years was relatively stable, suggesting the share of the secondary industry in the gross product increased increasingly faster. Yet after 2010, the contribution rate of industrial structure started to fall. China began to focus on industrial structure transformation and propel the supply-side structural reform.

The contribution of the industrial structure of Beijing, Liaoning, Heilongjiang, Shanghai, Yunnan and Zhejiang was negative, respectively \(-1.04 \times 10^8 t, -0.102 \times 10^8 t, -1.24 \times 10^8 t, -0.69 \times 10^8 t\) and \(-0.39 \times 10^8 t\), as shown in Figure 3. The industrial structure of these areas hindered the increase in carbon emission. In Beijing, Shanghai and Zhejiang, rapid economic growth and sizable investment in science and technology helped to gain more considerable efforts to develop new energy. Besides, the vigorous development of the service industry led to a decline in the proportion of the second industry. In Yunnan, tourism was the primary industry, and its development was driving the growth of the economy. Energy consumption
was small. Carbon emissions would be controlled. Otherwise, the contribution of the industrial structure in other energy-intensive provinces, such as Inner Mongolia and Shanxi, was positive and great, respectively $2.397 \times 10^8 \text{ t}$ and $2.31 \times 10^8 \text{ t}$. In these areas, energy consumption was very high. Economic development would be driven by the secondary industry. The industrial structure of these provinces enormously expedited the changes in carbon emissions.

Table I shows that changes in population around contributed to $13.64 \times 10^8 \text{ t}$, which caused the cumulative increase in carbon emissions, taking up 3.11 per cent. According to the National Bureau of Statistics of China, the population of the provinces has been growing from 2000 to 2014. According to the basic situation of China’s vast population base and the “Two Children” policy, the trend would continue. The large population would undoubtedly bring the increase in consumption, probably leading to augment in carbon emissions.

From 2000 to 2014, the overall population effect was positive. Yet the population effect of Jilin, Heilongjiang, Anhui, Henan, Hunan, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Gansu and Qinghai was negative, respectively, $-0.006 \times 10^8 \text{ t}$, $-0.067 \times 10^8 \text{ t}$, $-0.11 \times 10^8 \text{ t}$, $-0.14 \times 10^8 \text{ t}$, $-0.13 \times 10^8 \text{ t}$, $-0.11 \times 10^8 \text{ t}$, $-0.05 \times 10^8 \text{ t}$, $-0.09 \times 10^8 \text{ t}$, $-0.27 \times 10^8 \text{ t}$, $-0.296 \times 10^8 \text{ t}$, $-0.04 \times 10^8 \text{ t}$ and $-0.05 \times 10^8 \text{ t}$, as shown in Figure 4. This suggested that the population in these provinces hindered the increase in carbon emissions, while the population effect in other provinces increased carbon emissions. Thus, to efficiently deal with carbon emissions, the population of the provinces with the positive effect should be controlled and the people of the regions with adverse impact should be encouraged.

Table I shows that, in the last 15 years, the energy structure had little contribution to carbon emissions, with the average contribution ratio of only 0.28 per cent. The overall impact of energy structure adjustment on carbon emissions was small. Before 2007, the contribution of the energy structure to carbon emissions showed an increase and underwent an obvious growth in 2003. At this stage, the energy structure intensified carbon emissions, and the degree was rising. China boosted rapid economic development primarily through the heavy industry, which would cause the increase of carbon emissions. But, beginning in 2008, the energy structure effect has been declining in the whole. After 2012, the energy structure effect became negative. The energy structure hindered the increase of carbon emissions, and the degree was rising. At this time, China started to stress the energy structure adjustment. The optimization and upgrading of energy structure had effectively hindered the increase of carbon emissions.

From 2000 to 2014, the overall energy structure effect was positive. Yet, provinces with adverse energy structure effects are more than those with positive energy structure effect, as shown in Figure 5. That is to say, every province had gradually made energy structure adjustment and had some improvement. In Shandong, Henan shannxi and Gansu, the contribution of energy structure is positive as $1.13 \times 10^8 \text{ t}$, $0.3 \times 10^8 \text{ t}$, $0.22 \times 10^8 \text{ t}$ and $0.24 \times 10^8 \text{ t}$, respectively. In these areas, reducing coal consumption and promoting the exploitation of new energy were the focus of development. China had the foundation for renewable energy sources and clean energy, such as wind power, geothermal and natural gas. The transformation of energy structure was achievable.

3.2 The optimal projection direction analysis

The optimal projection direction of carbon emissions indicators can be obtained using the projection pursuit method, as shown in Table III. The optimal projection direction could be
well described as the influence degree of various factor on carbon emissions. Taking each five-year plan as a stage, this paper analyzed the influence degree of various factor.

There is a difference in the influence degree of factors in various periods, as shown in Table III. In the period of "10th Five-Year" plan, the optimal projection direction of per capita carbon emissions in each year was the largest as 0.5998, 0.6122, 0.5234, 0.5740 and 0.5614. Besides, the optimal projection direction value of energy intensity and energy structure were also large. It could be argued that per capita carbon emissions, energy structure and energy intensity had a significant impact on carbon emissions in China in these five years. China was in a crucial period of rapid development. All aspects were in a significant growth trend. Energy consumption had also increased significantly, in particular the coal consumption, contributing to the increase of carbon emissions.

The impact of per capita GDP on carbon emissions was relatively small as 0.2759, 0.2705, 0.0335, 0.0554 and 0.0516. In the tenth five-year plan, economic development was relatively fast, whereas GDP was still relatively low, which caused a little effect on carbon emissions. As industrial development was not very mature, the impact of industrial structure on carbon emissions was not obvious.

In the "11th Five-Year" plan, except for 2007, the optimal projection directions of energy structure in 2006, 2009 and 2010 were relatively large, respectively, 0.7322, 0.6470, 0.4958, 0.6200, as shown in Table III. In these four years, energy structure was the primary factor affecting carbon emissions. Due to the Beijing Olympic Games, all over the country were reducing carbon emissions and controlling pollution, so the consumption of coal fell sharply. Energy structure had undergone huge changes, which had a significant impact on carbon reduction.

Besides, the optimal projection direction values of per capita carbon emissions and energy intensity were also large. Energy intensity would also drop significantly with the decline of high-polluted energy consumption. Thus, carbon emissions were affected by the change of energy intensity. The sustained growth of the population accelerated the increase of carbon emissions.

In the "12th Five-Year" plan, the optimal projection direction of energy structure in each year was the largest as 0.6186, 0.6454, 0.5827, 0.6673, as shown in Table III. Besides, the optimal projection direction value of the industrial structure is also large. It could be argued

<table>
<thead>
<tr>
<th>Years</th>
<th>Per capita carbon emissions</th>
<th>Energy intensity</th>
<th>Energy structure</th>
<th>Industrial structure</th>
<th>Per capita GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.5892</td>
<td>0.5539</td>
<td>0.4083</td>
<td>0.3819</td>
<td>0.1767</td>
</tr>
<tr>
<td>2001</td>
<td>0.5998</td>
<td>0.3557</td>
<td>0.6533</td>
<td>0.1041</td>
<td>0.2759</td>
</tr>
<tr>
<td>2002</td>
<td>0.6122</td>
<td>0.4000</td>
<td>0.2853</td>
<td>0.5573</td>
<td>0.2705</td>
</tr>
<tr>
<td>2003</td>
<td>0.5234</td>
<td>0.6652</td>
<td>0.5241</td>
<td>0.0886</td>
<td>0.0335</td>
</tr>
<tr>
<td>2004</td>
<td>0.5740</td>
<td>0.6412</td>
<td>0.5016</td>
<td>0.0682</td>
<td>0.0554</td>
</tr>
<tr>
<td>2005</td>
<td>0.5614</td>
<td>0.5334</td>
<td>0.5748</td>
<td>0.2593</td>
<td>0.0516</td>
</tr>
<tr>
<td>2006</td>
<td>0.3317</td>
<td>0.5043</td>
<td>0.7322</td>
<td>0.3089</td>
<td>0.0645</td>
</tr>
<tr>
<td>2007</td>
<td>0.7247</td>
<td>0.4481</td>
<td>0.1918</td>
<td>0.4704</td>
<td>0.1268</td>
</tr>
<tr>
<td>2008</td>
<td>0.4798</td>
<td>0.4460</td>
<td>0.6470</td>
<td>0.3878</td>
<td>0.0421</td>
</tr>
<tr>
<td>2009</td>
<td>0.5146</td>
<td>0.5179</td>
<td>0.4958</td>
<td>0.4677</td>
<td>0.0490</td>
</tr>
<tr>
<td>2010</td>
<td>0.4024</td>
<td>0.4576</td>
<td>0.6200</td>
<td>0.4927</td>
<td>0.0392</td>
</tr>
<tr>
<td>2011</td>
<td>0.5440</td>
<td>0.3237</td>
<td>0.6186</td>
<td>0.4154</td>
<td>0.2099</td>
</tr>
<tr>
<td>2012</td>
<td>0.4700</td>
<td>0.3320</td>
<td>0.6454</td>
<td>0.4972</td>
<td>0.0712</td>
</tr>
<tr>
<td>2013</td>
<td>0.3354</td>
<td>0.4600</td>
<td>0.5827</td>
<td>0.5781</td>
<td>0.0467</td>
</tr>
<tr>
<td>2014</td>
<td>0.3652</td>
<td>0.3854</td>
<td>0.6673</td>
<td>0.5152</td>
<td>0.0856</td>
</tr>
</tbody>
</table>
that in these five years, energy structure and industrial structure had a crucial impact on carbon emissions in various provinces. The “12th Five-Year Plan” required to adjust the industrial structure, vigorously develop the service industry, reduce the development of primary energy and energetically develop clean energy and new energy. Energy structure and industrial structure have been optimized. Carbon emissions from the consumption of coal and the high-energy consumption industry had been significantly reduced.

Energy intensity and per capita GDP had little impact on carbon emissions. The pace of economic growth had been slowed down, but the total economy had been on the rise. Per capita GDP did not undergo obvious change, resulting in the little impact on carbon emissions. The impact of energy intensity on carbon emissions also was not large.

3.3 Prediction analysis
Based on the optimal projection direction of 2000 to 2014, the optimal projection direction prediction value of 2015 to 2020 was obtained using Markov transfer matrix, as listed in Table IV.

From the horizontal perspective, the optimal projection direction of each index in the six years from the largest to the smallest is energy structure, industrial structure, per capita carbon emissions, energy intensity, per capita GDP, as shown in Table IV. The trend of each index remains stable. Energy structure and industrial structure still will have the greatest impact on carbon emissions in the next few years. The exploitation and utilization of clean energy, as well as the development of the tertiary industry, turn out to be the developing trends of the present and the next few years. Carbon emissions will be directly controlled.

From the vertical view, the optimal projection direction of energy intensity has been risen steadily from 2015 to 2020 year, while the optimal projection direction of the industrial structure has been fluctuated, but roughly stable. By 2020, energy restructuring would be basically mature. Even in some economically backward and energy-intensive areas, industrial structure optimization and upgrading are also basically completed. The industrial reorganization has not been critical for the control of carbon emissions. As a result, the impact of the industrial structure on carbon emissions has been fallen from 2015 to 2020 year. With the continuous improvement of energy efficiency, energy intensity is, therefore, declining, which plays an important role in carbon emissions control.

4. Conclusions and policy implications
In this paper, carbon emissions from 2000 to 2014 in China were analyzed using the projection pursuit and Markov model. Through the LMDI decomposition model, several factors affecting carbon emission were identified, i.e. per capita carbon emissions,

<table>
<thead>
<tr>
<th>Year</th>
<th>per capita carbon emission</th>
<th>Energy intensity</th>
<th>Energy structure</th>
<th>Industrial structure</th>
<th>per capita GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>0.4727</td>
<td>0.3968</td>
<td>0.5654</td>
<td>0.5364</td>
<td>0.1083</td>
</tr>
<tr>
<td>2016</td>
<td>0.4364</td>
<td>0.4262</td>
<td>0.6190</td>
<td>0.4870</td>
<td>0.0872</td>
</tr>
<tr>
<td>2017</td>
<td>0.4727</td>
<td>0.4237</td>
<td>0.5846</td>
<td>0.4946</td>
<td>0.1033</td>
</tr>
<tr>
<td>2018</td>
<td>0.4618</td>
<td>0.4320</td>
<td>0.6000</td>
<td>0.4798</td>
<td>0.0997</td>
</tr>
<tr>
<td>2019</td>
<td>0.4735</td>
<td>0.4321</td>
<td>0.5887</td>
<td>0.4811</td>
<td>0.1055</td>
</tr>
<tr>
<td>2020</td>
<td>0.4712</td>
<td>0.4354</td>
<td>0.5929</td>
<td>0.4753</td>
<td>0.1052</td>
</tr>
</tbody>
</table>

Table IV. The best projection direction prediction value in 2015-2020
industrial structure, energy intensity, energy structure and per capita GDP. Based on the projection pursuit method, the optimal projection directions of five influencing factors in 30 provinces (except for Tibet) were acquired, and the difference of the optimal projection direction of each element in 2003, 2008 and 2013 was studied. The weight of each index in the next five years was predicted, and the corresponding suggestions were proposed using the Markov transfer matrix according to the data from 2000 to 2014. Specific conclusions are as follows:

- Based on the LMDI decomposition model, five influencing factors were determined (e.g. per capita carbon emissions, industrial structure, energy intensity, energy structure and per capita GDP). Based on the 2000 year, the contribution rates of the five influencing factors to the carbon emissions in the period from 2001 to 2014 were analyzed. The contribution of per capita GDP to carbon emissions was the most prominent (Xu et al., 2016); energy intensity has negative impact on carbon emissions, which is a crucial factor in the reduction of carbon emissions. The contribution of energy structure and industrial structure to carbon emissions was changed from negative to positive and increased generally. The decomposition results of this paper were consistent with the study of Shao et al. (2014) and Liu et al. (2015).

- The classification standards of 30 provinces (except for Tibet), the optimal projection direction of the five factors, were obtained using the projection pursuit model, reflecting the degree of various influencing factors on carbon emissions in different years. Given the national policy, the paper analyzed the change of the influence degree on carbon emissions of five indicators in three periods.

- The relative weight values of the five indexes in the next six years were predicted using the Markov transfer matrix according to the optimal projection direction of each index from 2000 to 2014. Moreover, the relative weight difference of the optimal projection direction was not significant and relatively stable.

Based on the noted findings, the policy of promoting energy savings and emission reduction in the process of economic development is continuously supposed to be improved and constructed. Specific recommendations are as follows:

- Improve energy structure and proactively develop renewable energy. Greater attempt should be made to vigorously adjust and improve the energy structure in various regions, especially Gansu, Heilongjiang and other provinces with relatively rich energy resources but backward economic progress. Green energy and clean energy should be vigorously developed and exploited to decrease the share of high-carbon energy consumption. Besides, it is necessary to vigorously facilitated building energy saving, encourage the use of energy-saving appliances and reduce the energy consumption of the unit production.

- Pay more attention to readjusting industrial structure of the provinces and autonomous regions. Tertiary industries (e.g. the tourism and services industry) should be vigorously developed. The government should adjust the industrial structure, making it gradually transfer from resource-intensive to intelligence-intensive. The disparity of economic development in China is prominent, so it is indispensable to formulate various industrial structure adjustment policies and measures for the actual situation of each province in China. For the provinces in the process of transferring from the primary industry to the secondary industry, they
should adhere to the road of sustainable development and prioritize the improvement of the technology level and the utilization of clean energy. For some of the more developed provinces, they should attach importance to developing high-tech industry, new energy industry and modern service industry. For the provinces prioritizing the traditional coal production or high-energy consuming heavy industry, the efficiency of existing technology should be proactively improved, and the clean industry should be actively facilitated.

- Reasonably control the coal production and improving energy efficiency. The government should limit the scale of high-energy-consuming production enterprises. The advanced technology should be introduced to increase the energy efficiency (e.g. coal moisture control). For the traditional coal production enterprises, the development of other renewable energy or green energy could be gradually improved, which would contribute to control carbon emissions.
- Establish an effective regional cooperation mechanism among the provinces in China (Renukappa et al., 2013). For those provinces with low total CO₂ emissions and fast the deterioration, the government should stress its CO₂ emissions reduction based on the condition of CO₂ emissions reduction in the provinces. The establishment of CO₂ emissions accounting and comparison system is urgently required. Furthermore, relevant professionals are needed, and guide is required.

In general, this paper studied the factors affecting carbon emissions and acquired the current and future influence degree of various factors, which is of great significance to the low-carbon development in China. Due to the limitations of research experience and various conditions, the following aspects should be improved: first and foremost, carbon emission factors should be further refined. There are vast factors affecting carbon emission, and more accurate data should be collected to further analyze and discuss. Second, to predict the influence degree of each factor in the next few years, the selected data remain minimal, and the predicted results may have some limitations. Accordingly, the further study may make more in-depth and accurate predictions based on the index weight for more consecutive years.

References


Further reading


Corresponding author
Lei Wen can be contacted at: wenlei0312@126.com
Climate change and crop farming in Bangladesh: an analysis of economic impacts

Mohammad Shakhawat Hossain and Lu Qian
College of Economics and Management, Northwest Agriculture and Forestry University, Yangling, China

Muhammad Arshad
Institute of Socio-economics, Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany

Shamsuddin Shahid
Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia

Shah Fahad
College of Economics and Management, Northwest Agriculture and Forestry University, Yangling, China, and

Javed Akhter
Department of Physics, Jadavpur University, Kolkata, West Bengal, India

Abstract

Purpose – Changes in climate may have both beneficial and harmful effects on crop yields. However, the effects will be more in countries whose economy depends on agriculture. This study aims to measure the economic impacts of climate change on crop farming in Bangladesh.

Design/methodology/approach – A Ricardian model was used to estimate the relationship between net crop income and climate variables. Historical climate data and farm household level data from all climatic zones of Bangladesh were collected for this purpose. A regression model was then developed of net crop income on climate variables.

© Mohammad Shakhawat Hossain, Lu Qian, Muhammad Arshad, Shamsuddin Shahid, Shah Fahad and Javed Akhter. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode

The first author wishes to acknowledge Chinese Scholarship Council (CSC), Government of China, for providing financial support for postgraduate studies in China. Moreover, this work is supported by the National Natural Science Foundation of China (Project Nos. 71673223 and 71473197). The authors are grateful to Dr Robert Mendelsohn, Yale University, School of Forestry and Environmental Studies, New Haven, USA, for providing valuable feedbacks from inception to the final write-up of the paper. The authors also extend their sincere thanks to the editors of the journal and the anonymous reviewers for their valuable comments and suggestions that have significantly improved the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.
income per hectare against long-term climate, household and farm variables. Marginal impacts of climate change and potential future impacts of projected climate scenarios on net crop incomes were also estimated.

**Findings** – The results revealed that net crop income in Bangladesh is sensitive to climate, particularly to seasonal temperature. A positive effect of temperature rise on net crop income was observed for the farms located in the areas having sufficient irrigation facilities. Estimated marginal impact suggests that 1 mm/month increase in rainfall and 10°C increase in temperature will lead to about US$4-15 increase in net crop income per hectare in Bangladesh. However, there will be significant seasonal and spatial variations in the impacts. The assessment of future impacts under climate change scenarios projected by Global Circulation Models indicated an increase in net crop income from US$25-84 per hectare in the country.

**Research limitations/implications** – The findings of this study indicate the need for development practitioners and policy planners to consider both the beneficial and harmful effects of climate change across different climatic zones while designing and implementing the adaptation policies in the country.

**Originality/value** – Literature survey of the Web of Science, Science Direct and Google Scholar indicates that this study is the first attempt to measure the economic impacts of climate change on overall crop farming sector in Bangladesh using an econometric model.

**Keywords** Bangladesh, Climate change, Adaptation, Crop farming, Net crop income, Ricardian model

**Paper type** Research paper
the Meghna along with their numerous tributaries (World Bank, 2010). Because of this natural geographic design, the country faces severe floods on a regular basis. The floods of 1974, 1984, 1987, 1988 and 1991 were most destructive and caused loss of human lives and serious damage to agricultural production (Agrawala et al., 2003). Besides, its position between the funnel-shaped Bay of Bengal in the south and the world’s highest mountain Himalayas in the north has made the country a place of intensive monsoon rainfalls, cyclones, floods, storm surges etc. (Ferdous and Baten, 2011). After the catastrophic cyclones of 1970 and 1991, cyclone Sidr of 2007, for example, was among the most devastating disasters in recent years. It caused a loss of 3,295 lives and destroyed approximately 1.5 million households and 2.2 million hectares of cropland. The total damage was estimated at about US$1.67bn (International Federation of Red Cross and Red Crescent Societies (IFRC, 2010). It has been projected that country will experience more frequent and natural disasters in near future due to climate change (IPCC, 2007).

A sharp rise in temperature and changes in rainfall patterns are already evident in Bangladesh (Shahid, 2010; Shahid et al., 2012). The average daily temperature in Bangladesh has increased by 0.103°C per decade over the past four decades (Shahid, 2010). There have also been reports of changes in spatial variability and seasonal pattern in rainfall (Shahid and Khairulmaini, 2009). The projections say that temperature of Bangladesh will continue to increase by 1°C by 2030, 1.4°C by 2050 and 2.4°C by 2100 due to global warming (IPCC, 2007). Rising temperature will enhance evapotranspiration and air moisture holding capacity which in turn will change the annual and seasonal variability of rainfall and their spatial distributions. Such changes in climate can have severe impacts in an agro-based country like Bangladesh, where more than 55 per cent of the total population directly depends on agriculture, and 17.22 per cent of the gross domestic product (GDP) comes from this sector (Bangladesh Bureau of Statistics (BBS, 2015). Crop farming is the primary source of food for 149.77 million people and accountable for food security both in urban and rural populations (BBS, 2015).

Considering the vulnerability and sensitivity of Bangladeshi agriculture sector to climate change, this paper attempts to answer the important questions:

Q1. Does climate change affect net incomes from crop farming sector in Bangladesh?

Q2. Will crop farming in Bangladesh be profitable under future climate change scenarios?

Q3. What are the necessary steps for the government policy planners to minimize the negative impacts of climate change on crop farming?

However, to answer these questions, studies in this direction are still insufficient. Only a few studies have been conducted in recent years to assess the impact of climate change on agriculture in Bangladesh (Sarker et al., 2012; Amin et al., 2015; Chowdhury and Khan, 2015). Amin et al. (2015) reported the significant impact of different climate variables namely, temperature, rainfall, humidity, and sunshine on the yield of major food crops (rice and wheat). Sarker et al. (2012) studied the relationships among maximum temperature, minimum temperature, and rainfall with three varieties of rice crops and found a significant impact of climatic variables on the productivity of rice. However, the focus of most of the previous studies was limited to climatic impacts on selected food crops. To date, no study has been conducted to measure the economic impacts of climate change on overall crop farming in Bangladesh. Some studies have already been conducted in the neighboring
countries such as Sri Lanka, India and Pakistan to assess the economic impacts of climate change on agriculture (Seo et al., 2005; Kumar, 2011; Mishra et al., 2015; Arshad et al., 2016). All the studies reported the significant impacts of climate change on agriculture, but a wide variability in loss and gain in different regions. This emphasizes the need for assessment of climate change impacts on crop farming and their spatial variability in Bangladesh.

The primary objective of this study is to assess the long-term impacts of climate change on net incomes from crop farming in Bangladesh. To achieve this, we used Ricardian regression models using a unique dataset of 420 farm households located across different climatic zones of the country. We also analyzed the marginal impacts of climate change and the potential future impacts of different climate scenarios on net crop incomes. Finally, based on the analytical findings, we suggest some policy measures that may enhance the adaptive capacity of the country’s farming systems in response to climate change. The rest of the paper is structured as follows: Section 2 presents the materials, methods, and data, Section 3 discusses the results, and Section 4 conclusions.

2. Materials and methods

2.1 Location of the study

Bangladesh (latitude: 20°34′N-26°38′N; longitude 88°01′E-92°41′E) (Figure 1) has a tropical monsoon climate distinguished by heavy seasonal rainfall, high temperatures, and high humidity. The average annual rainfall fluctuates from 1,500 mm in the west-central to over 3000 mm in the southeast and northeastern parts of the country. More than 70 per cent of total rainfall in Bangladesh occurs during monsoon (July to September). The mean summer and winter temperature ranges from 30 to 40°C and 18 to 22°C respectively, whereas April is the hottest and January is the coldest month [Bangladesh Meteorological Department (BMD), 2016]. Based on climatic conditions, the land of Bangladesh has been divided into 7 climatic zones, as shown in Figure 1. There are two distinct cropping seasons: Rabi (mid-November to mid-March) and Kharif (mid-March to mid-November). The Kharif season is further subdivided into two parts namely Kharif-I (mid-March to mid-July) and Kharif-II (mid-July to mid-November). Common Kharif crops include Aus and Aman rice, jute, and summer vegetables, while the Rabi crops include Boro rice, wheat, potato, pulses, oilseeds, and winter vegetables.

2.2 Data

2.2.1 Primary data. The primary data used in this study were collected using a disproportionate stratified random sampling technique to have a representative sample across all 7 climatic zones in Bangladesh (Arshad et al., 2016). The climatic zones shown in Figure 1 were used as a basis for stratification. Each climatic zone was treated as one stratum. Three administrative districts were selected from each stratum randomly (Figure 2). From each selected district, two Upazilas (lower administrative units) were randomly selected whereas one village from each Upazila and ten farm households from each village were subsequently selected randomly. This resulted in 60 farm households from each climatic zone, totaling 420 respondents across all climatic zones. The selected districts represent a broad degree of agro-climatic, socio-economic and geographic features of Bangladesh.

The data were collected through field surveys conducted between January 2017 and April 2017 considering the cropping seasons of 2015-16. The survey questionnaire was designed to collect detailed information on the socio-economic characteristics of the sampled households including basic household information (gender, farmer’s age, education, household size etc.), and the farm characteristics which include farming experience, farm area, soil types, access to bank credit, distance to market, access to extension services, and irrigation facilities. We also collected information on farmers’ perceptions about climate
change and changes in the local climatic patterns observed by farmers over the past decades. In addition, we collected information on current adaptation measures undertaken by the farmers in the study area (Table III). Net crop income per hectare is a core variable of Ricardian regression analysis. To estimate net crop income, farmers were asked in detail about their agriculture management practices, input and output costs. These include crop types, growing seasons of different crops, transportation and miscellaneous cost, cost and amount of inputs such as labor, irrigation, seeds, pesticide, fertilizer etc.

2.2.2 Secondary data. We collected 46 years (1971-2016) climate data on monthly average temperature and monthly average rainfall from the Bangladesh Meteorological Department, Dhaka. These climate data were interpolated from the respective meteorological stations located in the surveyed districts and climatic zones under the study. After testing a number of alternative definitions of seasons, dry (November-March) and wet (April-October) seasons were considered for the analysis. Due to the country’s geographical location and small areal extent, average winter (21.16°C) and summer (28.11°C) temperatures of Bangladesh do not vary significantly. The dry (Rabi) and wet (Kharif) seasons are also the coldest and the hottest seasons respectively.

2.3 Ricardian methodology
The relationship between climate and agriculture is typically modeled using three approaches: crop growth simulation models, agro-economic models, and integrated...
assessment models such as computable general equilibrium and whole farm models (Mishra et al., 2015). The basis of these models is on climate-crop physiology and development. The first two modeling approaches can include some adaptation and crop management practices such as change of planting dates, variety selection, and fertilizer use. However, as both the modeling approaches are crop-specific, they are unable to account for other adaptation measures such as responses to economic stimuli including input replacement, price variations, crop shifting, and multi-cropping. Without accounting for such behavioral responses, those approaches can lead to an overestimation or underestimation of the climate impacts.

Source: Government of Bangladesh (2014)
For the development of an unbiased estimate of climate impacts, there is a need for a whole farm approach that allows for adaptation responses. The model that is currently being widely used across different countries to measure the economic impacts of climate change in the agriculture sector is the “Ricardian model”, named after the work of economist David Ricardo (1772-1823). Mendelsohn et al. (1994) was the pioneer to develop this cross-sectional model. The basis of the model is on the observation that land rents capture the long-term productivity of the farm. The Ricardian model assesses the performance of farms across landscapes, capturing impacts of spatial variations in climate attributes and other factors including input prices, soils, and socio-economic factors where the value of the lands reflects the present value of the future stream of net farm income.

The main advantage of this model is that it accounts for adaptation because farmers tend to adapt to the climate where they live to maximize the outputs and farm incomes. Other important advantages of the model are:

- it does not require data over time which is very difficult and costly to collect, rather it needs data across geographic space where climate attributes vary;
- it is a flexible model as it allows to consider all major enterprise activities; and
- it is very easy to implement.

However, the Ricardian model has some limitations. The first drawback is the possibility of omitted variable bias, which is present in all cross-sectional analysis. Another concern is the inefficiencies of the land and labor prices/markets that may distort prices. It does not account for CO₂ fertilization effects. Furthermore, the model cannot capture transition costs of an instantaneous adaptation to a new technology against climate. However, sudden adaptation to new technology is never experienced. Another controversial drawback is concerned with irrigation (Schlenker et al., 2005). It is also not an issue in the study area as maximum farms rely on irrigation (Shahid, 2010).

### 2.4 Empirical model specification

Following Mendelsohn et al. (1994), we specified the Ricardian model as:

\[
V = f(C, H, F)
\]  

(1)

Where \( V \) is the net crop income per hectare; \( C \) is a vector of climate variables (temperature and rainfall); \( H \) is a set of household attributes that includes age and education of the respondents, household size, and farming experience; and \( F \) is a set of farm variables, including farming area, access to extension services, distance to market, access to farm credit, soil types, and access to irrigation. We define net crop income as the total crop income (farm gate price multiplied by quantity sold) less the total cost of production that includes the cost of hired labor, fertilizer, pesticide, seeds, irrigation, and transport. Net crop income was calculated by the following equation:

\[
V = \sum P_i Q_i (X, C, H, F) - \sum P_x X
\]

(2)

Where \( P_i \) is the market price of crop \( i \), \( Q_i \) is the output of crop \( i \), \( X \) is a quantity of all inputs purchased for producing of crop \( i \), \( P_x \) is a vector of input prices respectively. The standard Ricardian model relies on the quadratic formulation of climate:

\[
V = \beta_0 + \beta_1 C + \beta_2 C^2 + \beta_3 H + \beta_4 F + u
\]

(3)
Where $C$ and $C^2$ capture the levels and quadratic terms for climate variables respectively, while $u$ is an error term. The quadratic term is included to capture the nonlinear relationships. If a positive number for the quadratic term is obtained, the function assumes a U-shaped form, whereas if the value is negative, the function assumes a hill-shape form.

From equation (3), we estimated the marginal impacts of a change in temperature and rainfall on net crop income, which can be specified as follows:

$$\frac{\partial NR}{\partial T} = \beta_1 + 2\beta_2 T \quad \text{and} \quad \frac{\partial NR}{\partial R} = \beta_3 + 2\beta_4 R$$

(4)

3. Results and discussion

STATA (version 14.0) was used to analyze the data and run the Ricardian model. Summary statistics of the climate and other variables are presented in Tables I, II and III. The endogeneity problem was countered by using reduced form model rather than the structural model. As we can only minimize the multicollinearity at a certain level, we omitted age variable which was correlated with the farming experience. We also excluded distance to market variable from our analysis as it was found statistically insignificant. To minimize the heteroscedasticity, a robust estimation was applied for estimating standard errors. In case of outliers, we excluded 24 households assumed to be outliers as they reported very high or very low income and very large or very small farm size.

3.1 Climate variables and net crop income

The regression coefficients estimated from the two Ricardian models are presented in Table IV. In the first model, we estimate the seasonal temperature and rainfall (with quadratic terms) data on net crop income alone. In the second model, we include farm and

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net crop income (US$/Ha)</td>
<td>410.34</td>
<td>249.95</td>
</tr>
<tr>
<td>Temperature wet season (in degree Celsius)</td>
<td>28.11</td>
<td>0.53</td>
</tr>
<tr>
<td>Temperature dry season (in degree Celsius)</td>
<td>21.16</td>
<td>0.98</td>
</tr>
<tr>
<td>Rainfall wet season (in Millimeter)</td>
<td>300.38</td>
<td>106.21</td>
</tr>
<tr>
<td>Rainfall dry season (in Millimeter)</td>
<td>20.88</td>
<td>8.79</td>
</tr>
<tr>
<td>Gender (gender of the farmer)</td>
<td>0.97</td>
<td>0.18</td>
</tr>
<tr>
<td>(1 = male, 0 = female)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farmers’ age (years)</td>
<td>48.39</td>
<td>9.24</td>
</tr>
<tr>
<td>Farmers’ education (years of schooling)</td>
<td>6.11</td>
<td>2.17</td>
</tr>
<tr>
<td>Farm household size (number of household members)</td>
<td>6.15</td>
<td>1.42</td>
</tr>
<tr>
<td>Farming experience (years of experience)</td>
<td>26.49</td>
<td>9.05</td>
</tr>
<tr>
<td>Access to bank credit (yes = 1, No = 0)</td>
<td>0.40</td>
<td>0.49</td>
</tr>
<tr>
<td>Access to agricultural extension services</td>
<td>0.80</td>
<td>0.40</td>
</tr>
<tr>
<td>(yes = 1, No = 0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to irrigation (yes = 1, No = 0)</td>
<td>0.64</td>
<td>0.48</td>
</tr>
<tr>
<td>Distance to market (Kilometers)</td>
<td>2.60</td>
<td>1.27</td>
</tr>
<tr>
<td>Sandy soil (dummy variable)</td>
<td>0.27</td>
<td>0.44</td>
</tr>
<tr>
<td>(Sandy soil = 1, non-sandy soil = 0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay soil (dummy variable)</td>
<td>0.10</td>
<td>0.29</td>
</tr>
<tr>
<td>(Clay soil = 1, non-clay soil = 0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm size (hectare)</td>
<td>1.79</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Table I. Summary statistics for the variables used in the analysis (sample size $n = 396$)
household characteristics variables to control for additional extraneous elements that may affect crop output and income.

The results from both the models are robust. The estimated models explain 3 to 16 per cent of the observed variations in net crop income hectare and most of the parameters in the models have expected signs. We observed that the constant values are very high even though they do not hold much statistical value. The reasons may be the low number of observations and few explanatory variables. Climate variables showed a nonlinear relationship with net crop incomes which is consistent with the findings of recent Ricardian studies available (Kabubo-Mariara and Karanja, 2007; Mishra et al., 2015; Arshad et al., 2016; Huong et al., 2018). The wet and dry season temperatures showed an upward and downward trend respectively which is somewhat surprising. But given that these two temperatures (wet and dry) are part of the summer cropping season (Kharif) and winter cropping season (Rabi), respectively. The summer cropping season in Bangladesh is a combination of the significant part of the spring, summer and fall, while the winter cropping season is a combination of the winter and earlier part of spring. Higher temperature in the earlier part of wet season may be beneficial because it helps in primary growth and development of crops, while a warmer climate in the later stages can have harmful effects, e.g. slowing down of crop growth. This might be reason that the wet temperature indicated an inverted U-shaped trend.

On the contrary, the relatively low temperature in the early stages of dry season may be detrimental to crop growth, but as it gets warmer in the later stages, it becomes beneficial for ripening and maturity of crops. Thus, dry temperature indicated a U-shape trend. However, in case of rainfall, the trends for wet and dry seasons were found hill-shaped which indicates that early stage rainfall in both seasons is favorable for crop farming in

<table>
<thead>
<tr>
<th>Name of climatic zones</th>
<th>Mean net crop income (US$/Ha)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>South-central</td>
<td>381.04</td>
<td>239.87</td>
</tr>
<tr>
<td>South-western</td>
<td>456.21</td>
<td>232.47</td>
</tr>
<tr>
<td>Western</td>
<td>473.16</td>
<td>296.86</td>
</tr>
<tr>
<td>North-western</td>
<td>420.46</td>
<td>319.95</td>
</tr>
<tr>
<td>Northern part of the north region</td>
<td>405.33</td>
<td>239.23</td>
</tr>
<tr>
<td>South-eastern</td>
<td>370.18</td>
<td>186.29</td>
</tr>
<tr>
<td>North-eastern</td>
<td>366.02</td>
<td>228.59</td>
</tr>
<tr>
<td>Average</td>
<td>410.34</td>
<td></td>
</tr>
</tbody>
</table>

Table II. Variability in net crop incomes across 7 surveyed climatic zones

<table>
<thead>
<tr>
<th>Adaptation strategies</th>
<th>(%) of sample households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of new crop varieties</td>
<td>52</td>
</tr>
<tr>
<td>Adjusting sowing dates</td>
<td>48</td>
</tr>
<tr>
<td>Crop diversification</td>
<td>33</td>
</tr>
<tr>
<td>Change in cropping pattern and rotations</td>
<td>21</td>
</tr>
<tr>
<td>Integrated farming systems</td>
<td>16</td>
</tr>
<tr>
<td>Moved to non-farm activities</td>
<td>13</td>
</tr>
<tr>
<td>Find off-farm job</td>
<td>11</td>
</tr>
<tr>
<td>Other strategies</td>
<td>13</td>
</tr>
</tbody>
</table>

Table III. Current adaptation strategies practiced by the farmers apart from irrigation

Note: Columns may sum to >100% where farmers reported more than one adaptation measure
Bangladesh. Our findings are somewhat consistent with those of the South African crop farming analysis conducted by Benhin (2008).

Among the households’ socio-demographic variables, the farming experience was positively associated with net crop income ($p < 0.05$) which suggests that experienced farmers are a better custodian of their land and may have good knowledge and information on the changes in local climatic conditions. For example, applying various soil conservation practices or using modern agricultural technologies, they are able to adapt to weather fluctuations and climatic variability (Huong et al., 2017; Mishra and Pede, 2017). In line with this rationale, access to irrigation facilities was also significantly and positively correlated with net crop income ($p < 0.05$). Farmers widely use irrigation especially groundwater irrigation to hedge against drought and heat stress, which also plays an important role to increase the productivity and hence net crop incomes in Bangladesh (Shahid, 2010). However, groundwater level in many regions of Bangladesh is declining due to higher abstraction, which may cause an increase in salinity and irrigation cost and eventually may affect farmers’ income in the long run (Krupnik et al., 2017).

The positive and significant influence of farm size on net crop income ($p < 0.01$) indicates the economies of scale that large farms are associated with higher productivity compared to small ones. A similar result was found by Nyoor et al. (2016) in a study of northern Ghana. Access to agricultural extension services is also positively associated with net crop incomes ($p < 0.1$). This result implies that access to extension information and services increase farmers’ knowledge on crop management practices and hence the capacity to adapt to the changes in climate to improve their outputs and incomes (Joshi et al., 2017; Trinh et al., 2017). The coefficient of soil types indicate that both sandy and clay soils are associated with lower net incomes. However, only clay soil was found statistically significant ($p < 0.1$).

### Table IV.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 1 Coefficient</th>
<th>Robust $t$-statistics</th>
<th>Model 2 Coefficient</th>
<th>Robust $t$-statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature wet season</td>
<td>-13367.93***</td>
<td>-2.84</td>
<td>-11318.51**</td>
<td>-2.28</td>
</tr>
<tr>
<td>Temperature wet season squared</td>
<td>241.07***</td>
<td>2.86</td>
<td>205.42**</td>
<td>2.31</td>
</tr>
<tr>
<td>Temperature dry season</td>
<td>2656.94***</td>
<td>2.93</td>
<td>3060.22***</td>
<td>3.60</td>
</tr>
<tr>
<td>Temperature dry season squared</td>
<td>-62.83***</td>
<td>-2.97</td>
<td>-72.31***</td>
<td>-3.63</td>
</tr>
<tr>
<td>Rainfall wet season</td>
<td>6.19***</td>
<td>3.43</td>
<td>7.04***</td>
<td>3.95</td>
</tr>
<tr>
<td>Rainfall wet season squared</td>
<td>-0.00***</td>
<td>-3.16</td>
<td>-0.00***</td>
<td>-3.58</td>
</tr>
<tr>
<td>Rainfall dry season</td>
<td>27.44*</td>
<td>1.91</td>
<td>26.17*</td>
<td>1.86</td>
</tr>
<tr>
<td>Rainfall dry season squared</td>
<td>-0.52</td>
<td>-1.56</td>
<td>-0.50</td>
<td>-1.56</td>
</tr>
<tr>
<td>Farmer’s educational level</td>
<td>8.11</td>
<td>1.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farming experience</td>
<td>3.86**</td>
<td>2.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm household size</td>
<td>10.74</td>
<td>1.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to agricultural extension services</td>
<td>50.11*</td>
<td>1.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to bank credit</td>
<td>19.71</td>
<td>0.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to irrigation</td>
<td>46.40**</td>
<td>2.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm size</td>
<td>56.80***</td>
<td>3.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay soil</td>
<td>-50.55*</td>
<td>-1.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy soil</td>
<td>-18.04</td>
<td>-0.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>156,177.10***</td>
<td>2.57</td>
<td>121,768.89*</td>
<td>1.90</td>
</tr>
<tr>
<td>$n$</td>
<td>396</td>
<td></td>
<td>396</td>
<td></td>
</tr>
<tr>
<td>$F$</td>
<td>3.21***</td>
<td></td>
<td>2.81***</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.0358</td>
<td></td>
<td>0.1653</td>
<td></td>
</tr>
</tbody>
</table>

Notes: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$
3.2 Estimates of marginal impacts

The results of the marginal impacts of climate variables on net crop incomes per hectare are presented in Table V. A 1°C increase in temperature during the wet season would result in an income gain of about US$15.64 per hectare while in the dry season it would cause a decrease of net income by about US$0.22 per hectare. The higher temperature in summer cropping season would negatively affect the net incomes due to the strong seasonal effect of the fall season. Increasing temperature in the earlier part of the summer cropping season would be helpful for crop growth, but the temperature rise in later part would be destructive to crop farming unless farmers are conscious of this seasonal effect and adapt their farming activities accordingly. On the contrary, higher temperature in winter cropping season would have a positive effect on net incomes due to the strong seasonal influence of the spring season.

The marginal impacts of increasing rainfall will lead to an increase in net incomes in both the wet and dry seasons. The total impact of a 1°C increase in temperature and 1 mm/month increase in rainfall would cause an increase in income by US$19.66 per hectare across all climatic zones of the country. However, higher rainfall in the summer cropping season would have a minimal positive impact on net incomes. This result implies that early rainfall in the summer cropping season would be more helpful to crop growth than the excessive rainfall in the later stages. Thus, the timely arrival of the summer monsoon and its regularity are crucial for crop production in Bangladesh. On the other hand, rainfall in the winter cropping season is statistically significant ($p < 0.05$). The implication of increasing rainfall in the winter cropping season would also be helpful for crop growth, output and hence the enhancement of net incomes. The results indicate that seasonal variations are a vital factor for net income in both the cropping seasons. A similar observation has been reported by Benhin (2008) in the South African climate context. Table V also indicates that net crop income is more elastic to the changes in temperature (1.13 per cent) than the rainfall (0.42 per cent).

The results of the marginal impact of temperature are quite interesting. As a humid tropical warm region, one would anticipate that an increase in temperatures would lead to a

<table>
<thead>
<tr>
<th>Variable</th>
<th>Full model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1°C increase in temperature on net crop income (US$/Ha)</strong></td>
<td></td>
</tr>
<tr>
<td>Temperature wet</td>
<td>15.64</td>
</tr>
<tr>
<td>Summer cropping season</td>
<td>-54.23</td>
</tr>
<tr>
<td>Temperature dry</td>
<td>-0.22</td>
</tr>
<tr>
<td>Winter cropping season</td>
<td>33.46</td>
</tr>
<tr>
<td>Annual temperature</td>
<td>15.42</td>
</tr>
<tr>
<td>Annual elasticity</td>
<td>1.13</td>
</tr>
<tr>
<td><strong>1 mm/month increase in rainfall on net crop income (US$/Ha)</strong></td>
<td></td>
</tr>
<tr>
<td>Rainfall wet</td>
<td>0.30</td>
</tr>
<tr>
<td>Summer cropping season</td>
<td>0.34</td>
</tr>
<tr>
<td>Rainfall dry</td>
<td>3.94***</td>
</tr>
<tr>
<td>Winter cropping season</td>
<td>4.23**</td>
</tr>
<tr>
<td>Annual rainfall</td>
<td>4.24</td>
</tr>
<tr>
<td>Annual elasticity</td>
<td>0.42</td>
</tr>
<tr>
<td>Total climate</td>
<td>19.66</td>
</tr>
</tbody>
</table>

Table V. Marginal impacts of climate on net crop incomes (US$/Ha)

Notes: **$p < 0.05$; US$1 = 80.64 BDT considering average exchange rates during the survey
decrease in net incomes. Our analyses however revealed that net crop income increases with rising temperatures. The reasons may be the ample rainfall in monsoon and availability of groundwater resources which permit a very high fraction of irrigated farmland in Bangladesh (Shahid, 2010). Extensive use of groundwater irrigation and improved technologies enable farmers in the region to endure much higher temperatures. Shahid (2010) in his study on Bangladesh interestingly reported that climate change will increase daily use of water for irrigation by an amount of 0.88 mm/day at the end of this century. With irrigation, higher temperatures have led to more cropping seasons per year which helped farmers to increase their net incomes. Thus, Bangladesh’s agriculture appears to be adapting against warming and will be benefitted mildly even in a warmer world. This is consistent with the study of Mendelsohn (2008), he reported that wet eastern regions of India (geographical position of Bangladesh is within this region) will benefit gently from the global warming. Our findings are also consistent with those from Southeastern China which show similar trends and robustness (Wang et al., 2009).

### 3.3 Marginal impacts of climate across all climatic zones

To examine the distribution of impacts across different climatic zones, the marginal impacts of climate for each zone are calculated from the coefficients of the Ricardian regression model (Van Passel et al., 2016). The obtained results are presented in Table VI. Estimated marginal impacts of temperature showed that most of the climatic zones would experience a positive effect on net incomes though the coefficients for all climatic zones are not statistically significant. The results of the positive effect of temperature rise on net incomes may be due to the use of different adaptation techniques undertaken by the farmers in the study area as discussed above. A 1°C increase in temperature will lead to an increase in annual net incomes between $11 (USD) to $48 (USD). Alternatively, the relatively colder climate zones such as south-eastern and north-eastern Bangladesh would experience a negative mean annual impact of US$9.51-16.31 per hectare respectively. Among the seven climatic zones, the western zone which is characterized by hot climate would gain the

<table>
<thead>
<tr>
<th>Climate zones</th>
<th>Wet season</th>
<th>Dry season</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1°C increase in temperature on net crop income (US$/Ha)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South-central</td>
<td>13.90</td>
<td>-2.68</td>
<td>11.22</td>
</tr>
<tr>
<td>South-western</td>
<td>40.38</td>
<td>-17.06</td>
<td>23.32</td>
</tr>
<tr>
<td>Western</td>
<td>39.08</td>
<td>9.24</td>
<td>48.32</td>
</tr>
<tr>
<td>North-western</td>
<td>11.30</td>
<td>12.64</td>
<td>23.94</td>
</tr>
<tr>
<td>Northern part of the north region</td>
<td>6.96</td>
<td>19.45</td>
<td>26.41</td>
</tr>
<tr>
<td>South-eastern</td>
<td>19.85</td>
<td>-29.36</td>
<td>-9.51</td>
</tr>
<tr>
<td>North-eastern</td>
<td>-23.85</td>
<td>7.54</td>
<td>-16.31</td>
</tr>
<tr>
<td><strong>1 mm/month increase in rainfall on net crop income (US$/Ha)</strong></td>
<td>0.33</td>
<td>3.89**</td>
<td>4.22</td>
</tr>
<tr>
<td>South-central</td>
<td>0.41</td>
<td>3.94**</td>
<td>4.35</td>
</tr>
<tr>
<td>South-western</td>
<td>0.41</td>
<td>4.67*</td>
<td>5.08</td>
</tr>
<tr>
<td>Western</td>
<td>0.35</td>
<td>5.01</td>
<td>5.36</td>
</tr>
<tr>
<td>North-western</td>
<td>0.31</td>
<td>5.40</td>
<td>5.71</td>
</tr>
<tr>
<td>Northern part of the north region</td>
<td>0.20*</td>
<td>3.21**</td>
<td>3.41</td>
</tr>
<tr>
<td>South-eastern</td>
<td>0.08</td>
<td>1.48</td>
<td>1.56</td>
</tr>
</tbody>
</table>

**Notes:** **p < 0.05; *p < 0.1**

Table VI. Marginal impacts of climate across the all zones.
highest US$48.32, indicating that higher temperatures increase net crop income in the zone. The reasons may be that the farmers of this region have already adjusted their crop management practices to changing climatic conditions such as increased irrigation applications to offset the effects of heat stress. The marginal impact of increased rainfall in the dry season showed positive relations with net crop incomes across all zones and most of them are statistically significant in different levels ($p < 0.05$ and $p < 0.1$) in comparison to the results of the wet season rainfall.

These results establish that the marginal impacts are not uniformly distributed and that there would be losses and gains due to climate change across the different climatic zones. It is therefore essential for policy planners to reduce the losses and to take benefit of the gains by selecting and assessing the efficiency of existing adaptation mechanisms and finding ways to support them.

### 3.4 Climate projections and its impacts on net crop incomes

We then examined the impacts of future climate change on crop farming in Bangladesh. In this connection, future changes in rainfall and surface temperature for each district were first estimated using two Coupled Atmospheric Oceanic General Circulation Models (AOGCMs). These models are the Beijing Normal University Earth System Model: BNU-ESM (Ji et al., 2014) and the Canadian Earth System Model: CanESM2 (Chylek et al., 2011). The data were downloaded from the Coupled Model Intercomparison Project Phase 5 (CMIP5) website (http://pcmdi9.llnl.gov). Simulated daily surface rainfall and mean temperatures from each model were averaged to produce estimates of monthly mean climatological changes (absolute temperature changes and relative percentage rainfall changes) for the periods 2021-2060 and 2061-2100 (relative to the historical 1971-2005) under an assumed Representative Concentration Pathway RCP8.5 (van Vuuren et al., 2011).

Future projections of annual temperature and rainfall over Bangladesh and its impacts on net crop incomes are presented in Table VII. The estimates showed that both models forecasted increasing temperatures for Bangladesh in the range of 1.81-2.04°C by 2021-2060 and even higher levels of 3.68-4.47°C by 2061-2100 periods. In case of rainfall, BNU-ESM projected decreasing rainfall levels (4.8 per cent) by 2021-2060 whereas increasing trend is observed (5.47 per cent) by 2061-2100 periods. However, CanESM2 projected increasing rainfall levels (3.39-19.97 per cent) during the both periods. By using parameters of the fitted net income model of Table IV, we estimated the impacts of these AOGCM scenarios on net incomes for these two time-periods. It is observed that the increment in the net income per hectare is more in the period of 2061-2100 than 2021-2060 under both scenarios.

Moreover, to compare the distribution of impacts across the different climatic zones, impact estimates for each climatic zone are estimated at the mean of a climate variable at that agro-climatic zone (Seo et al., 2005). The findings are presented in Table VIII. The result indicated that different climatic zones would not be uniformly affected by the future climate

<table>
<thead>
<tr>
<th>Climate projection models</th>
<th>Change in temperature °C</th>
<th>(%) Change in rainfall</th>
<th>Change in net incomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNU-ESM: 2021-2060</td>
<td>1.81</td>
<td>-4.80</td>
<td>24.77 (6.04)</td>
</tr>
<tr>
<td>CanESM2: 2021-2060</td>
<td>2.04</td>
<td>3.39</td>
<td>44.29 (10.79)</td>
</tr>
<tr>
<td>BNU-ESM: 2061-2100</td>
<td>3.68</td>
<td>5.47</td>
<td>60.82 (14.82)</td>
</tr>
<tr>
<td>CanESM2: 2061-2100</td>
<td>4.47</td>
<td>19.97</td>
<td>93.82 (22.86)</td>
</tr>
</tbody>
</table>

Note: Percentage changes in parenthesis.
change. This finding is in line with the results by Seo et al. (2005). The results also reveal that the gains from the future climate change for the welfare of Bangladeshi farmers would be increase over the years as they would continue to use irrigation as a cushion for adverse climate effects.

4. Conclusions
This paper is an endeavor to assess the economic impacts of climate change on crop farming in Bangladesh using a Ricardian regression model. The regression results indicate that farmers’ current net incomes are sensitive to climate. Seasonal temperature has a more pronounced effect on net incomes than seasonal rainfall. Farm and household characteristics including the availability of extension services, farm size, access to irrigation and farming experience were positively associated with net incomes, while clay soils were found to hurt net incomes. Subsequent estimates of marginal impacts revealed that crop net income is more elastic to changes in temperature than rainfall but with significant seasonal and spatial variations in impacts. The impacts of climate change projected by two AOGCMs namely, BNU-ESM, CanESM2 reveal that net crop income in Bangladesh would increase in the range of US$25-84 per hectare. The distribution of net income impacts indicated that different climatic zones will not be equally affected by future changes in climate.

The results of our study may guide the government policy makers and rural development practitioners in designing the appropriate adaption strategies in the country. Adaptation policies should target different climatic zones based on the constraints and potentials of each zone in lieu of recommending uniform interventions. To increase the resilience of crop farming sector of Bangladesh, immediate actions are required taking the current and anticipated climate change impacts into consideration. Based on the findings, our study suggests some essential climate adaptation policy recommendations which the government and policy makers may consider to address the challenges that farmers are likely to face as a result of climate change. Such recommendations include strengthening research capacity for the development of new cultivars and farming techniques with the changes in climate, enhancement of various enterprise diversification activities, making provision of crop insurance program and strengthening agricultural extension systems for disseminating up-to-date agricultural adaptation technologies to the farmers. Diversifying and generating off-farm employment opportunities in rural Bangladesh may also be crucial measures for the sustenance of rural masses. The present study was focused only on climate change impacts on net crop incomes. Future studies may consider analyzing the climate change impacts on other agricultural sectors, e.g. fisheries and livestock to assess the economic benefits or losses. We also suggest more research efforts in future for in-depth

<table>
<thead>
<tr>
<th>Climatic zones</th>
<th>BNU-ESM 2021-2060</th>
<th>CanESM2 2021-2060</th>
<th>2061-2100</th>
<th>2061-2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>South central</td>
<td>20.55 (5.00)</td>
<td>56.60 (13.79)</td>
<td>38.78 (9.45)</td>
<td>89.60 (21.84)</td>
</tr>
<tr>
<td>South-western</td>
<td>23.44 (5.71)</td>
<td>68.83 (16.77)</td>
<td>52.29 (12.74)</td>
<td>101.82 (24.81)</td>
</tr>
<tr>
<td>Western</td>
<td>58.50 (14.26)</td>
<td>94.55 (23.04)</td>
<td>78.02 (19.01)</td>
<td>126.67 (30.87)</td>
</tr>
<tr>
<td>North-western</td>
<td>34.42 (8.39)</td>
<td>70.47 (17.17)</td>
<td>53.94 (13.15)</td>
<td>103.47 (25.22)</td>
</tr>
<tr>
<td>Northern part of north</td>
<td>37.24 (9.08)</td>
<td>73.28 (17.86)</td>
<td>56.75 (13.83)</td>
<td>106.28 (25.90)</td>
</tr>
<tr>
<td>South-eastern</td>
<td>–1.29 (4.31)</td>
<td>34.76 (8.47)</td>
<td>18.23 (4.44)</td>
<td>67.76 (16.51)</td>
</tr>
<tr>
<td>North-eastern</td>
<td>–9.64 (2.35)</td>
<td>26.40 (6.43)</td>
<td>9.86 (2.40)</td>
<td>59.40 (14.48)</td>
</tr>
</tbody>
</table>

**Table VIII.** Forecasted average net crop incomes (US $/Ha) across different climatic zones

**Note:** Percentage changes in parenthesis
analyses of the economic impacts of climate change on farm income at the rural household level using a more holistic approach.

References


Further reading

Corresponding author
Lu Qian can be contacted at: luqian@nwafu.edu.cn

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: permissions@emeraldinsight.com
Number 3

309 Editorial advisory board

310 The global carbon budget and the Paris agreement
   Olga Alcaraz, Pablo Buenestado, Beatriz Escribano, Barbara Sureda,
   Albert Turon and Josep Xercavins

326 Effects of China’s environmental policy on carbon emission efficiency
   Xiongfeng Pan, Xianyou Pan, Changyu Li, Jinbo Song and Jing Zhang

341 Who is quitting? An analysis of the dis-adoption of climate smart sorghum varieties
   in Tanzania
   Franklin Simtowe and Kai Mausch

358 Crop switching as an adaptation strategy to climate change: the case of Semien
   Shewa Zone of Ethiopia
   Yibekal Abebe Tessema, Jonas Joerin and Anthony Patt

372 Disinterested agents or mismatched plans? Public administration capacities and
   climate change responses in the least developing countries
   Sunil Tankha, Sunita Ranabhat, Laxmi Dutt Bhatta, Rucha Ghate and Nand Kishor Agrawal

392 Climate change and variability perceptions in Ga-Dikgale community in Limpopo
   Province, South Africa
   Enerst Shingai Chikosi, Shingirai Stanley Mugambiwa, Happy Mathew Tirivangasi and
   Sejabaledi Agnes Rankoana

406 Analysis of influencing factors of Chinese provincial carbon emissions based on
   projection pursuit model and Markov transfer matrix
   Lei Wen and Linlin Huang

424 Climate change and crop farming in Bangladesh: an analysis of economic impacts
   Mohammad Shakhawat Hossain, Lu Qian, Muhammad Arshad, Shamsuddin Shahid,
   Shah Fahad and Javed Akhter