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Socio-economic consequences of climate change in Hindu-Kush Himalaya

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Abstract: The answer to how climate change will affect Hindu-Kush-Himalaya depends on whom you ask. Some will point at expected changes in climate, others will show what it may do to poor people, and some will express their concerns regarding the economies in the region. This report combines the three perspectives, and assesses the economic impacts of climate projections in China, India, Pakistan, Nepal, and Bangladesh to 2050. We further explore the consequences for smallholders of the projected changes in climate and resulting impacts on the socioeconomic drivers, based on survey in a local community in Nepal. The study points out reasons to expect that climate change will most likely affect smallholders much harder than indicated by economic indicators for their countries. Economic growth can be a successful way to improve the resilience of the population, but only if it benefits the poorest.

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Contents

Summary

There are many reasons to pay attention to impacts of climate change in Hindu-Kush-Himalayas. The cold climate at high latitudes indicates stronger temperature rise than in other parts of the world, and it is expected that the people in the area are particularly vulnerable to climatic changes. Therefore, a lot of research is going on to better understand the challenges, such as what climatic changes to expect, what impacts they will have on the nature, how they will affect people, and what can be done to increase the resilience of the people.

The many impacts of climate change depend closely on each other. To prepare for combining lessons from research of different aspects of climate change, the studies need to refer to the same climate projections, or to downscaled projections derived from the same global projections. How people and societies will be affected by climate change is not limited to changing climatic conditions and the resulting effects on nature, however. The vulnerability of a family is subject to their initial standard of living, which depends on a broad range of social and economic conditions. Some of them can be addressed by considering the community they are a part of, while others are subject to the interplay between communities and socioeconomic development in the country. Being a global issue, impacts of climate change on national conditions moreover depends on what happens in other countries. How to respond to climatic changes within a family thereby become subject to impacts on the national as well as global opportunities and constraints.

This report examines these interdependencies. The climate projections are based on the RCP8.5 emission pathways, and developed for the HICAP project. The emission pathways were run up to 2050, and it is shown how climate change is expected to affect the economies of China, India, Pakistan, Nepal and Bangladesh. Initially, the economic impacts can be traced to the effects on the demand for goods and services, to damages on real capital, to health effects on labour, and to the productivity of natural resources utilized for economic purposes. This leads to adaptation, first in directly affected sectors, but then to all the trading partners. Some of these are located within the five countries, and others are located in other countries. Thereby, the initial effects of climate change propagate to all economies in the world.

According to the climate projections, there will be a significant increase in average mean temperature until 2050 under the RCP8.5 pathway. Annual mean temperature will increase by approximately 1.3 °C in Hindu-Kush Himalayan regions of India, Pakistan, Bangladesh, and most regions in Nepal. In several Hindu-Kush Himalayan regions of China, and in two sparsely populated regions of Nepal, the temperature increase is between 1.5 and 2.0 °C. There are no clear trends in the change of annual precipitation, but seasonal variations may appear. However, seasonal variations are not captured by the estimated impacts on the national economies.

The underlying economic projections following RCP8.5 assume an annual average growth rate at 3 percent for the world economy until 2050, with 4.3 percent in China and 5.4 percent in India. A growth rate at 3 percent is assumed for the three other countries. In total, the economies of India and

Bangladesh are the most affected, where GDPs are reduced about 2 percent in 2050. Despite a higher increase in temperature, the GDPs of China and Nepal are only slightly affected. This is primarily because of small direct impacts to the economic activities. When worldwide adaptation and trade effects are taken into account, a small direct negative impact in China turns positive. Nepal experiences the opposite, where adaptation and trade turn an increase in GDP at 0.1 percent if market responses are ignored to a decrease at 0.3 percent if they are included. Worldwide adaptation and resulting impacts on trade worsen the economic consequences slightly also for India, while improving the consequences for Bangladesh a little.

The most significant difference between the direct impacts and the economic consequences appears in Pakistan, where worldwide adaptation and trade effects reduce the negative direct impact of 1.8 percent to 0.5 percent. This is most likely due to a big food industry in Pakistan. The food industry is less vulnerable to climate change than its main delivery sector, agriculture. The economy thereby takes more advantage of a significant increase in food prices than the economies of India and Bangladesh, where the direct impacts to agriculture are approximately the same. This appears both for impacts on GDP and for impacts on the terms of trade.

The impacts on the macroeconomic indicators are nevertheless moderate in 2050 for all five countries. This applies particularly to China, Pakistan and Nepal, even under the relative pessimistic emission pathway RCP8.5 considered here. This confirms findings in previous studies, which indicate that the impacts of climate change to the economies in all world regions are moderate even under RCP8.5 until the second half of this century (Aaheim et al., 2017). The negative economic consequences of climate change increase rapidly after 2050, and by the end of the century, the economies worldwide are radically unsustainable.

Moreover, the macroeconomic modelling is based on observations of economic transactions, and the impacts of climate change are translated to impacts on constraints of relevance for assessments of the impacts on economic markets. This is useful to indicate social and economic consequences in developed countries, where most of what people do for living is reflected by their monetary income, and their well-being can be related to what they buy for consumption. In developing countries, people’s well-being is poorly reflected by their consumption of marketable goods and services. Therefore, their behavior and related responses to changes cannot be explained as if all they produce and all they consume is reflected by their market transactions.

The agricultural output in national accounts is supposed to include consumption of goods produced on own farm, but it is an approximation, and highly uncertain. The weakness of using this in modelling is illustrated by comparing the contributions from the agricultural sector to GDP with the amount of people with agriculture as their main source of livelihood. In Nepal, for example, agriculture is the main activity for 78 percent of the population, but the production contribute to only 30 percent of GDP. 77 percent of the farmers live on farms smaller than 1 ha, where the main part of the production is consumed by the family members at the farm, and economic transactions are rare.

To address how smallholders are affected by the combination of climate change and resulting impacts on the economies, this study is amended by an analysis of smallholder farming, where the objectives of the farming is the same as that of farmers described by the macroeconomic model. However, farming among smallholders are constrained by the size of their farm. Their production depends on the farm size, consumption of food is divided into one part provided from the farm and one part bought in the market, and the farmers may work outside the farm if they have time left when the farming is done. Their income in monetary terms may thereby stem from work outside the farm and from sales of products from the farm.

The exploration of possible impacts to the smallholders are based on information from a survey of 60 farming households in Bamrang Khola in Khotang district. None of them had more than 2.25 ha of land available. The share of farms between 0.5 ha and 1.5 ha are higher in the survey than in Nepal on average, while the share below 0.5 ha in the survey was half the share in Nepal. The impacts were estimated under two climate scenarios, one referring to the climatic changes in Nepal used in the macroeconomic analysis, and one based on the same climate projections, but taken from the downscaling for the community of Bamrang Khola.

Climate change may affect the productivity of the land and the health of the smallholders. Using the same climate projections with the similar effects for Bamrang Khola as for Nepal in general, the productivity of land is reduced by 2.7 percent and health effects leads to a reduction of the productivity of the work by 2.4 percent in 2050. If the downscaled projections are used instead, the impacts on the productivity of land depends on how the local climate changes during the growing season for different crops. In that case, the productivity of land is hardly affected at all towards 2050, with an increase of 0.04 percent. On the other hand, a stronger increase in average temperature in Bamrang Khola than average for Nepal gives stronger health effects, with a 5.1 percent reduction in worker productivity.

According to the macroeconomic projections, climate change leads to a reduction of –0.05 percent in the contribution from agriculture to the Nepalese GDP in 2050. The small impact is partly due to an increase of 0.4 percent in relative prices of agricultural products. If impacts are the same in Bamrang Khola, those smallholders who are least affected will then have to reduce their consumption of food and other goods by approximately 2.5 percent, or 50 times the reduction in GDP. The reason is that most of the consumption of food among smallholders is from the farm, and therefore, they cannot take full advantage of higher prices.

Households on farms of different size are affected differently, depending on their specific constraints. The least affected smallholders are those who do not face constraints beyond their farm size and income. This applies to approximately 30 percent of the farmers. The remaining farms are constrained, either because they are among the 3 percent below the nutrition constraint, or because they belong to the 64 percent who would consume more food from own farm if they had a larger farm, or because transaction costs make it too expensive to hire people to work on their farm. The nearly 70 percent of farmers with farm size below the output constraint are worse off than those on unconstrained farms, because the price effect hits them harder. Farmers on unconstrained farms may compensate some of the loss in the productivity on land by working less on the farm and more outside the farm. Lower productivity of land on farms subject to the output constraint means that they are closer to a non-binding situation, but the output constraint is still binding, meaning that they are better off by working on the farm than compensating some of the loss by working more off the farm. In principle, some farms may change from a situation where they are subject to a binding constraint to a non-binding situation, but the impacts addressed in this study are not large enough to lead to a significant change in number of farms subject to the different constraints.

If we instead use the downscaled projections for the district of Bamrang Khola, the impacts in 2050 are due health effects only, but these are twice as strong as in the case with average impacts to Nepal. The smallholders are thereby hit more strongly. Consumption of food is reduced by 3 percent. Households on farms below the output constraint work equally much on the farm, but the productivity is lowered. The result is a reduction in the consumption of food from farm by less than 3 percent, but the consumption of food from market goes down by 6 percent. People on unconstrained farms can work more on the farm, and sell the products to compensate some of the loss of income from lower productivity. In general, however, the negative impacts are stronger in this case than in the former case, where the average impacts to Nepal are implemented.

The study shows a big difference between impacts of climate change on the national economies and on people in rural communities. This implies a challenge in developing adaptation strategies, because some initiatives have to be taken on the national level. Then, some impacts of climate change may have positive effects on the economy, but have significant negative impacts on most of the population. A main reason is that most smallholders are unable to take advantage of higher food prices, which is likely to follow a reduction in the productivity of land. The message to policy makers is, therefore, that economic development will clearly enhance adaptive capacity, but it has to be balanced such that poor people take advantage of it. A narrow focus on economic growth may make things worse.

1 Introduction

Climate change may have severe impacts in the Himalayan region. It is difficult to predict how the monsoon will be affected, but even small climatic changes may have dramatic impacts in the mountainous landscapes with a large poor and potentially vulnerable population. Research is taking place and advisory services are provided in the region to improve climate projections (Ren and Shestra, 2017), identify possible consequences and related challenges to people, and to facilitate adaptation (Xu et al., 2009).

The many challenges implies that a broad range of knowledge-based information is needed to tell what the future will look like. The messages from this knowledge refer to premises and assumptions, which differ depending on the underlying knowledge. Users need to combine lessons from different perspectives. They have difficulties in doing so, however, because the assumptions underlying the different studies are seldom clear to non-experts, and not often well coordinated among the experts. It is, therefore, unclear to users how they can combine messages from research of different perspectives to address the challenges they have in their everyday life. This limits the usefulness of the research.

An example is the different time perspectives taken in climate projections and in studies of the human responses to climate impacts, which are rarely discussed. To get clear signals of change in climate projections, one has to look at 2030 or 2040 at the earliest. Most studies of adaptation refer to observations of current activities in local communities, and ask what will happen in these communities if the local climate changes as described by the projected climate decades into the future. It is, of course, not only the climate that will change over these decades, but also the social and economic conditions, and different socioeconomic pathways give rise to different climatic changes. If the mutual dependencies between the economy and the climate are ignored, the lessons will be based on apparent inconsistencies, with unknown consequences.

This report explores how the socioeconomic drivers in combination with the derived climate projections may affect the impacts and vulnerabilities in communities in Hindu-Kush Himalayas. The aim is to point out how the socioeconomic development in the region may affect conclusions drawn from isolated local studies, and how insights from these studies may support development of national policies to facilitate adaptation in local communities.

We use climate projections consistent with a set of downscaled projections in HICAP (van Oort, 2014) to assess the related future economic development for the region from a macroeconomic model for the world, GRACE (Aaheim and Rive, 2005), where the economies of China, India, Pakistan, Nepal and Bangladesh are singled out. The macroeconomic model assesses the impacts of climate change on economic activities in various economic sectors and derives the effects on prices. This provides a consistent set of data for future changes in climate indicators and the economic drivers in the five countries, and shows how climate change will affect both the nature and the socioeconomic conditions to which people in local communities will have to adapt. The consequences for these people are addressed by a microeconomic model for smallholders, where we focus on farmers in Bamrang Khola community, in the district of Khotang in Nepal.

Things may change a lot in Bamrang Khola before climate has changed as described in this report. The messages are not meant as predictions of what will happen there, nor as recommendations to what they ought to do. The case study rather serves to illustrate logical consequences of the climate projections for the livelihood of people in communities similar to that of the present Bamrang Khola. The analysis of impacts and adaptation is based a general understanding of the behaviour of farmers. It is consistent with how economic behaviour is described in most economic models, but includes certain constraints under which smallholders are living. The aim is to combine insights from different research perspectives to provide a background for evaluating the social and economic consequences of climate change.

The report starts with a presentation of the economic models used in this report. Section 3 presents the climate projections that the study refers to, and explains how the output from the climate model were used. The macroeconomic consequences are analysed for China, India, Pakistan, Nepal and Bangladesh in Section 4. Section 5 presents the survey of farming in Bamrang Khola, and discusses the findings in light of the model for smallholders. Section 6 discusses impacts and challenges for smallholders, with reference to the findings from Bamrang Khola. The conclusions are drawn in Section 7.

2 Modelling and analytical approaches

Impacts of climate change make people and firms adapt by changing their priorities for what to produce, how to produce it and what to buy. Similarly, policies and specific measures often aim at making people and firms change their priorities. If one person, or a small group of people, is affected by a weather related event, the economic consequences may be assessed by considering the impacts to and responses by each of them. If they affect large groups, the change of priorities implies higher demand for some goods and services, and lower demand for others, meaning that the suppliers have to change their priorities in what to produce. This affects those who provide input to the production of these goods as well, and so on. In the end, the economic consequences of the initial climate impact or specific policy measures will affect the entire economy. The socioeconomic consequences of the economic interactions can be derived from general equilibrium models. In this report, such a model is combined with a microeconomic model to provide a more transparent link to observed choices among smallholders.

2.1 The macroeconomic perspective

The macroeconomic perspective is addressed by the computable general equilibrium model, GRACE (documentation and publications available at http://folk.uio.no/taoyuaw/grace.htm), which has been developed to assess the impacts of climate change and climate policy on macroeconomic indicators defined in national accounts. Computable general equilibrium models aim at quantifying the implications of economic interactions. The different ways people will be affected by climate change and the potential magnitude of the different impacts indicate that economic interactions will play an essential role in assessing the national implications of climatic changes and in developing appropriate policies. GRACE is calibrated on data provided by Global Trade Analyses Project, GTAP (Aguiar et al., 2016), which is based on national accounts data from the whole world. The data are adapted to attain consistent trade patterns across countries and to fit a unique set of definitions for economic activities and transfers. Figure 1 gives an overview of the statistical system and linkages in a given region of the model.

The GTAP data set comprises deliveries of goods from each sector to all other sectors (input factors) and to consumption and investments, as well as all financial flows. In the version used here, GRACE divides the economy of each country or region into 18 economic sectors, each producing one product. The composite of input from other sectors and the use of labour, capital and natural resources needed to produce the output in each sector can be associated with the technology within that sector.

The sum along the vertical axis in Figure 1 (green line) gives the total value of the output from the sector. The sum along the corresponding horizontal axis (red line) shows the total demand for this sector’s product. The data are used to calibrate demand functions from each sector and from consumers, based on specified production functions and welfare functions. Trade between countries and regions is modelled by dividing the deliveries of all goods into domestic and foreign deliveries. If the relative price between domestic and foreign deliveries change, the share of foreign deliveries will also change.

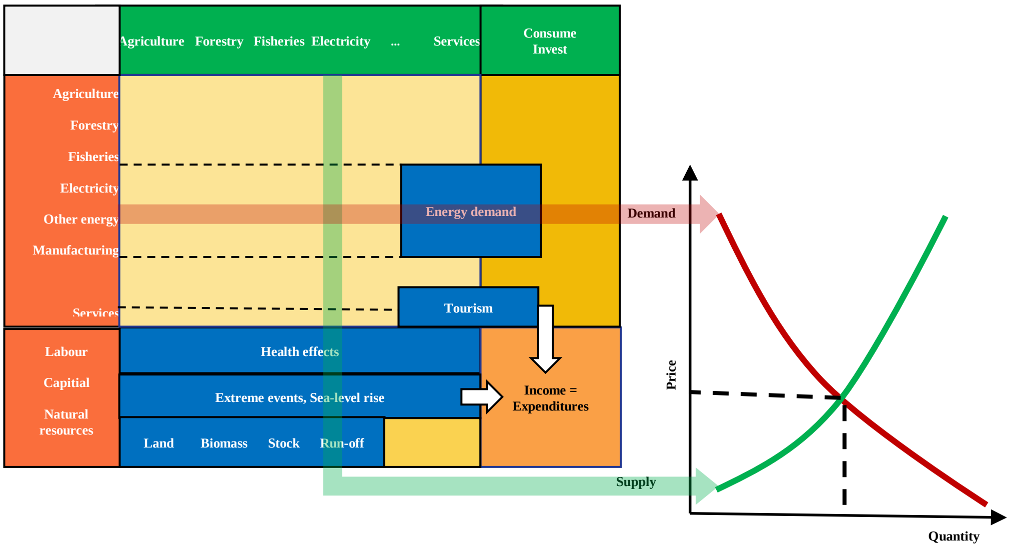


Figure 1. Use of primary resources and deliveries across sectors and end-use, with link to markets

To run the model, one needs projections of the drivers of economic growth; population growth, technological change, and investments. The results show how relative prices and quantities develop in all sectors and for the final deliveries when the total supply of each product from each region equals the total global demand, and that total income equals total expenditures in all regions, as illustrated in Figure 1. If the development of the abovementioned drivers of growth affect the demand for each good differently, prices will be adjusted to restore market equilibrium, which makes all economic agents adjust their demand for goods and services. A change in one single delivery thereby propagates to the entire economy, and the results show impacts on the main macroeconomic indicators defined in national accounts. Similarly, the model can be used to derive the impacts on the macroeconomic indicators of changes in the availability of resources, and of policy measures that either regulate the use and production of particular goods and services or create incentives to stimulate or prevent certain choices.

GRACE includes impacts of climate change by relating the availability of certain economic resources and the demand for selected goods and services to changes in mean temperature and changes in annual precipitation. The model includes nine impacts, indicated by the blue boxes in Figure 1. A change in temperature will affect the demand for energy goods, due to the needs for cooling and heating in the service sector and in households. In the model, this affects the demand for refined oil products and electricity. Impacts on tourism will lead to shifts in the demand for transport and some services. Both impacts are included in the service sector in the model version used here. The remaining seven impacts affect the primary input factors, labour, capital and natural resources. Temperature affects the productivity of labour. Capital, which includes invested technologies in the production sectors, buildings and infrastructure, may be affected by extreme events and sea-level rise, and the productivity of natural resources are affected in different ways in agriculture, forestry, fisheries and electric power generation.

The impacts of climate change are represented by impact functions in the model. These quantify the relationship between changes in climate indicators and the resulting change in the value of input or the value of consumption of the affected goods and services. There are relatively few assessments of costs on the national and regional scales of relevance for macroeconomic modelling. Cost assessments are usually provided as a metric amended to an estimate of the physical damage to show the importance of paying attention to the impacts of climate change, and to illustrate the potential savings of adaptation. The impact functions in the macroeconomic model describe, on the other hand, the effect on the entire sector aggregate, whose physical composite may change because of a change of scale. For example, if an aggregate consists of twenty cows and forty goats, the best way to double the production need not be to have forty cows and eighty goats. If it is less resource demanding to increase the production of goats than of cows, a doubling of the production implies more than eighty goats and less than forty cows. For the large aggregates represented in the macroeconomic model, the change in composites across scales may imply large differences between summing up bottom-up assessments of impacts and an assessment of the impacts on an aggregate.

The quantifications of impact functions refer partly to the assessment from the World Bank (Roson and Satory, 2016), and partly to a survey of impact assessments in different integrated assessment models, summarized in Aaheim et al. (2016a). Roson and Satory (2016) provide estimates for impacts at increasing temperatures on agriculture, energy supply and energy demand, tourism, sea-level rise and health for five countries in Hindu-Kush Himalaya; China, India, Pakistan, Nepal and Bangladesh. For the remaining impacts represented in GRACE, we use the estimates for East Asia (China) and for South Asia (India, Pakistan, Nepal, Bangladesh) in Aaheim et al. (2016a). For all impacts in the Rest of the World, we use a weighted average for all the other regions from Aaheim et al. (2016a).

The general form of all impact functions in all regions is a second-order polynomial:

$$dx_i = a_i dT^2 + b_i dT + c_i dP \tag{1}$$

Here, dx_i denotes the rate of change in the affected economic variable, such as the productivity of land. dT is the °C change in temperature, and dP is the rate of change in precipitation. a_i, b_i, and c_i are parameters calibrated to the estimated impacts from the two studies.

b is set equal to 0 for electricity supply and extreme events, while c is equal to 0 for all impacts except agriculture, forestry, electricity supply and tourism. All the impact functions are drawn in Appendix 1, which shows the impact on the variables indicated in Figure 1 at increasing temperatures. For agriculture, forestry, fisheries and the electricity sector, climate change will affect the productivity of the respective natural resources. Climate will also affect the demand for energy sources and for services related to tourism, while sea-level rise and extreme events cause damages to the stock of capital. Health effects reduce the productivity of labour, but differently for work outdoors and indoors. For each of the countries, the impact functions for health therefore differ between agriculture, manufacturing sectors and service sectors.

Note that while the rates of change depicted in the figures can be used to compare specific impacts on the different sectors across countries, they do not show the economic impacts to the economies, because these depend also on the relative contribution from the sector. Thus, even small changes in health effects or on the capital stock may have severe macroeconomic impacts, while relatively large impact on the availability of the different natural resources may be of limited importance, and vary considerably across countries and regions.

2.2 The perspective of smallholders

Agriculture constitutes the cornerstone of activities in the economies of Hindu-Kush Himalaya. To use statistics from the national accounts to explain farming practices in a macroeconomic model, one has to make sure that that those farmers addressed produce primarily with the aim of marketing their products. This is partly because national accounts are based on measures of economic transactions, and partly because the models explain market behaviour. The aim of most of the farming in Hindu-Kush Himalaya is, on the other hand, to provide food for a family living on the farm. Members of the households do not engage in farming because this is where their comparative advantage is in the labour market. They do so because they have to, but may be happy to be paid to work elsewhere, if possible. Therefore, poor households will be affected differently by climate impacts than farmers who specialize in supplying certain products for the markets. They also respond differently to climate impacts and to policies. Because of the limited interchange with markets, the market effects of these responses may be small, but what happens in the markets may have important implications to the poor.

This is the motivation for combining the macroeconomic model with a model for smallholders in this study. A formal presentation of the model for smallholders is given in Appendix 2. Figure 2 illustrates the focal points in the microeconomic model. It describes a family on a small farm where they produce different crops and have a small livestock. Most of what is produced on the farm is consumed by the family, but a part may be sold on a market place, as indicated by the green arrows. Most of the time is spent on work on the farm, but some of the time can be used to work outside the farm, either to set aside time to sell their products in the market or to work somewhere else, as indicated by the red arrows. The trade of own products and the income from other work brings the family into the (blue) economic market sphere, and allows them to buy goods and services not produced on the farm, as illustrated by the blue lines.

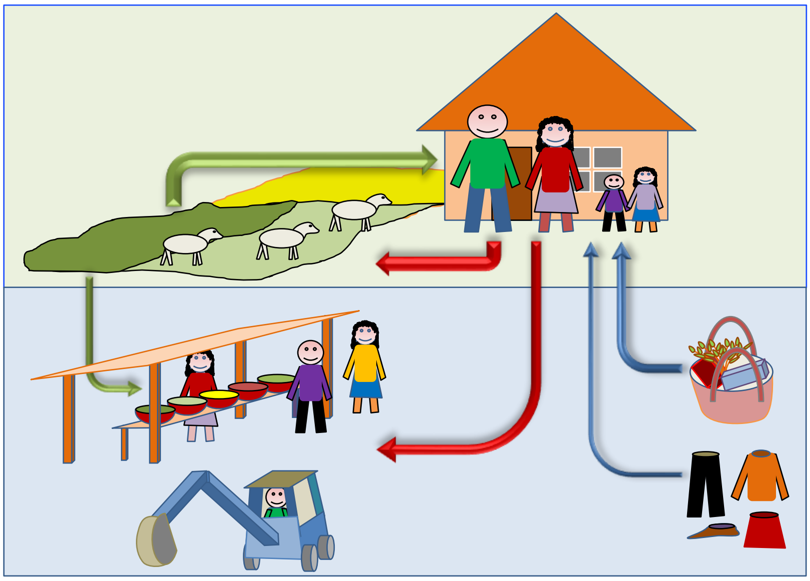


Figure 2. Focal points in the microeconomic model

Impacts of climate change may thereby affect the family in many ways. Most of the attention to impacts and challenges to adaptation among smallholders has been on changes in the quality of the land, and the effects on the productivity on the farm. This affects both the provision of food from own farm and deliveries to the market place. However, the income from the market will also depend on how other farmers are affected, as this may affect the food prices. Increasing food prices may increase the income from selling products from the farm, but will also increase the price of the food that the family has to buy in the market. Finally, the family is also affected by the impacts in other sectors and in the rest of the economy, because it may change the opportunity to earn an income from other work and the expenses to other goods than food.

The microeconomic model enables us to combine the direct effects of climate change to the activity on the farm with the broader socioeconomic consequences of climate change. Studies of how farmers in poor countries will be affected under a given downscaled projection of climate change, and what they can to do adapt can be implemented in the microeconomic model. Then, the market effects of these climate projections can be taken from the macroeconomic analysis, and the resulting effects on prices can be included in the microeconomic model to give a comprehensive picture of how smallholders will be affected.

Although the microeconomic model is meant to describe the situation for smallholders in general, results of studies in different communities may vary significantly across communities. To link it to a concrete case, a survey based on interviews with 60 households were done in Bamrang Khola, which is a part of Diktel municipality in Khotang, approximately 140 km east of Kathmandu. The results of the survey were used to quantify the relationships in the model presented in Appendix 2. Section 5 presents results from the survey and shows how they were used to quantify the microeconomic model.

3 Climate projections for Hindu-Kush Himalaya

The climate projections refer to dynamic downscaling by the Weather Research and Forecasting Model (WRF) (https://www.mmm.ucar.edu/weather-research-and-forecasting-model) in the Hindu-Kush region, which are based on global projections from Norwegian Earth System Model (NorESM) (http://folk.uib.no/ngfhd/EarthClim/). A comprehensive presentation of the projections is given in van Oort (2014).

It is necessary to simplify the information from the downscaled climate projections considerably to make them applicable for analyses of the economic impacts of climate change. This is mainly due to the different scales between data provided by the climate models and the data used in most economic analyses, and macroeconomic analyses in particular. The weather may change differently from one place to another place nearby, and over a short period. To capture regional and temporal variabilities under a changing climate, the global projections can be downscaled by separate models, and provide information on grids of a square kilometre or less, and with daily variations.

The economic consequences of changes in variability and sudden events may be substantial, and information about these changes is essential for deciding on how to prepare. From this perspective, the question is how expectations on future trends, changes in the variability and risks related to extreme events can be established with a transparent reference to the projections. This makes interpretations of the results from climate models essential, because no versions of GRACE are available yet that allows us to use the numbers directly. For studies of the macroeconomic consequences, where data are limited by geographical borders and in most cases provided for entire countries or world regions, one needs to interpret the consequences of the projections for the national aggregates of economic activities by sector. This section identifies the trends in changes of temperature and precipitation of the projections, assuming that a change in the frequency of extreme events is related directly to the estimated trends.

The global emission pathway is taken from RCP8.5 (van Vuuren et al., 2011). Global emissions of CO_2 increase over the whole century, between 1.5 and 2.0 percent per year from now to 2060. Between 2060 and 2080, the growth rate is reduced to between 0.5 and 1.0 percent, and further reduced to between 0.1 and 0.3 percent from 2080 to 2100, when emissions are about 2.5 times the present emissions. The resulting increase in global mean temperature is 5 °C above preindustrial level in this pathway.

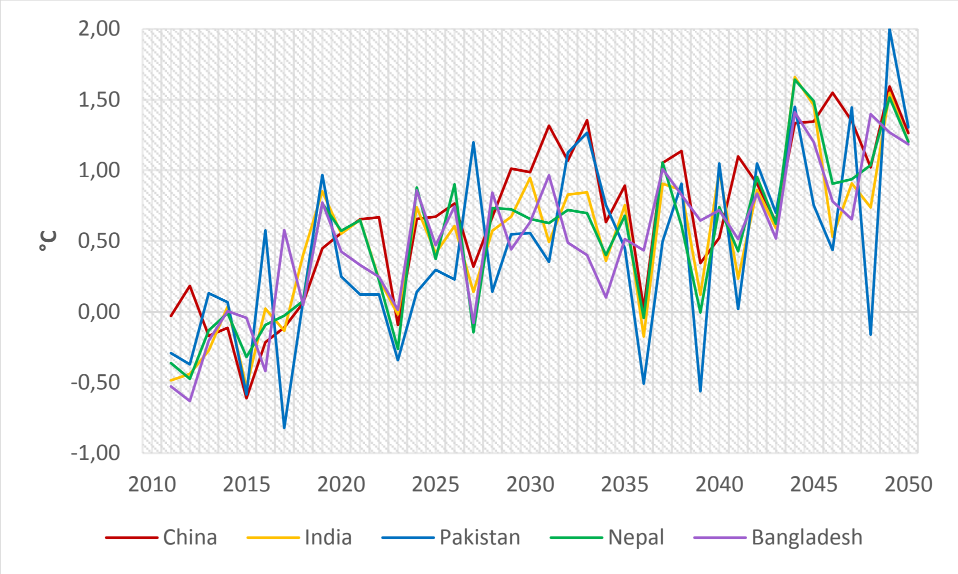


Figure 3. Change in mean temperature by country 2011 – 2050 in RCP8.5.

Figure 3 shows the projected change in average temperatures within the Hindi-Kush Himalayan regions in each country over the period 2011 to 2050, with 2010 as base year. The trends are quite clear, with the average temperature increasing between 1.0 °C and 1.5 °C during the period in all the countries, and perhaps with slightly more variations over time in Pakistan than in the other four countries.

It is not possible to identify similar trends for the development of annual average precipitation, which are shown in Figure 4. Precipitation varies considerably over time, however, and most in countries with a humid climate, such as Bangladesh and Nepal. In relative terms, variations are higher the dryer the climate is, with Pakistan as the driest among the countries addressed here. An exception is China, which has a relatively dry climate, but has a low variability over time also in relative terms.

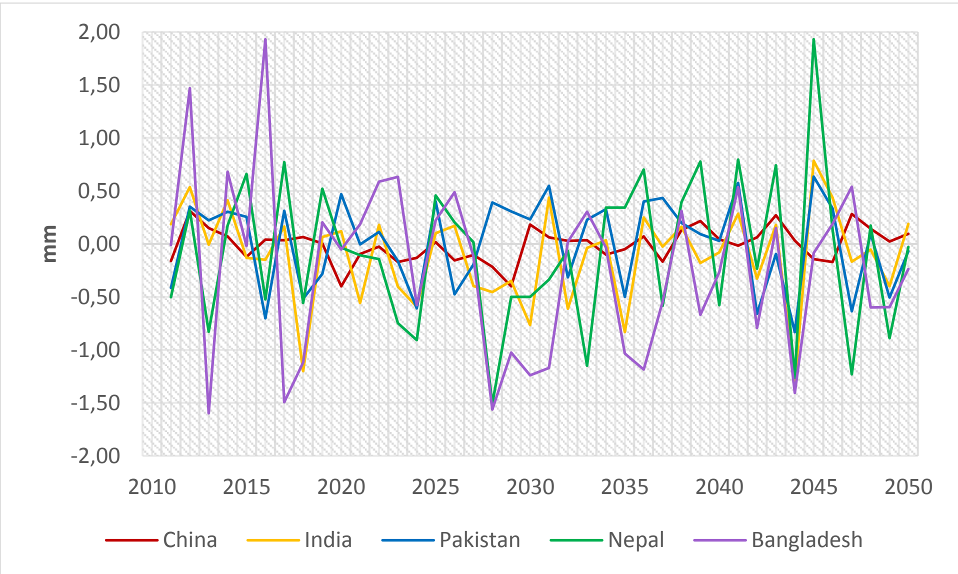


Figure 4. Change in mean precipitation by country 2011 – 2050 in RCP8.5. mm per day.

It is important to bear in mind that the projections for China, India and Pakistan cover only the parts of these countries that are included in the region of Hindu-Kush Himalaya, that is, the south-west part of China, mainly Tibet, the northern part of India, and the eastern part of Pakistan. On the other hand, the macroeconomic analyses are based on annual data of national aggregates, which cannot distinguish impacts on climatic changes across regions within the countries. Therefore, nearly all the information about the geographical resolution in the projections get lost.

Since we are addressing climate impacts to economic activities, geographical differences can, to some extent, be taken into account by identification of where the economic activities take place. To do so, the grids from the projections were divided into ten groups, each covering the decile of the population that lives in a grid within the same density interval. The mean temperatures and precipitation used in the impact functions were then weighted by the number of grids in each decile. Climatic changes in an urban area thereby count more that the changes in an equally large rural area.

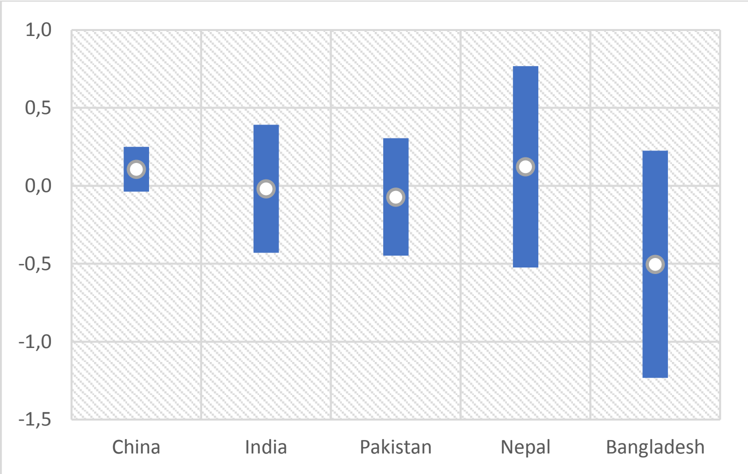


Figure 5. 90 percent confidence interval in annual average precipitation 2011 – 2050 by country. mm per day.

With one exception, there are no clear patterns in the change in annual precipitation across areas within each country. The exception is a medium densely populated set of grids in China, where there is a significant, but relatively small increase in precipitation. As indicated by Figure 4, there is no such pattern in average precipitation for the country either. Figure 5 gives 90 percent confidence intervals for change in annual mean precipitation in each country. What appears is a narrow interval in China, and much more uncertainty in Nepal and Bangladesh, perhaps an expected dryer climate in Bangladesh.

The changes in temperatures are significant for all areas with the same population densities in all countries. Figure 6 shows a 90 percent confidence interval for the increase in temperature during the period 2011 – 2050 in all categories from low population density (d1) to high population density (d10). The darkest part of each bar indicates the expected increase. For China, India and Pakistan, some deciles of population densities were empty because only a part of the country is covered by the projections. In the economic analyses, we have used the average for the included grids for these parts of the countries.

The increase in temperatures is approximately the same across regions in India, Pakistan and Bangladesh, with an expected increase between 1.2 °C and 1.3 °C in all regions. The variations between the deciles are larger in China and Nepal, between 1.0 °C and 1.8 °C in China, and between 1.2 °C and 1.7 °C in Nepal. In both countries, the highest temperature increase is in the least densely populated areas.

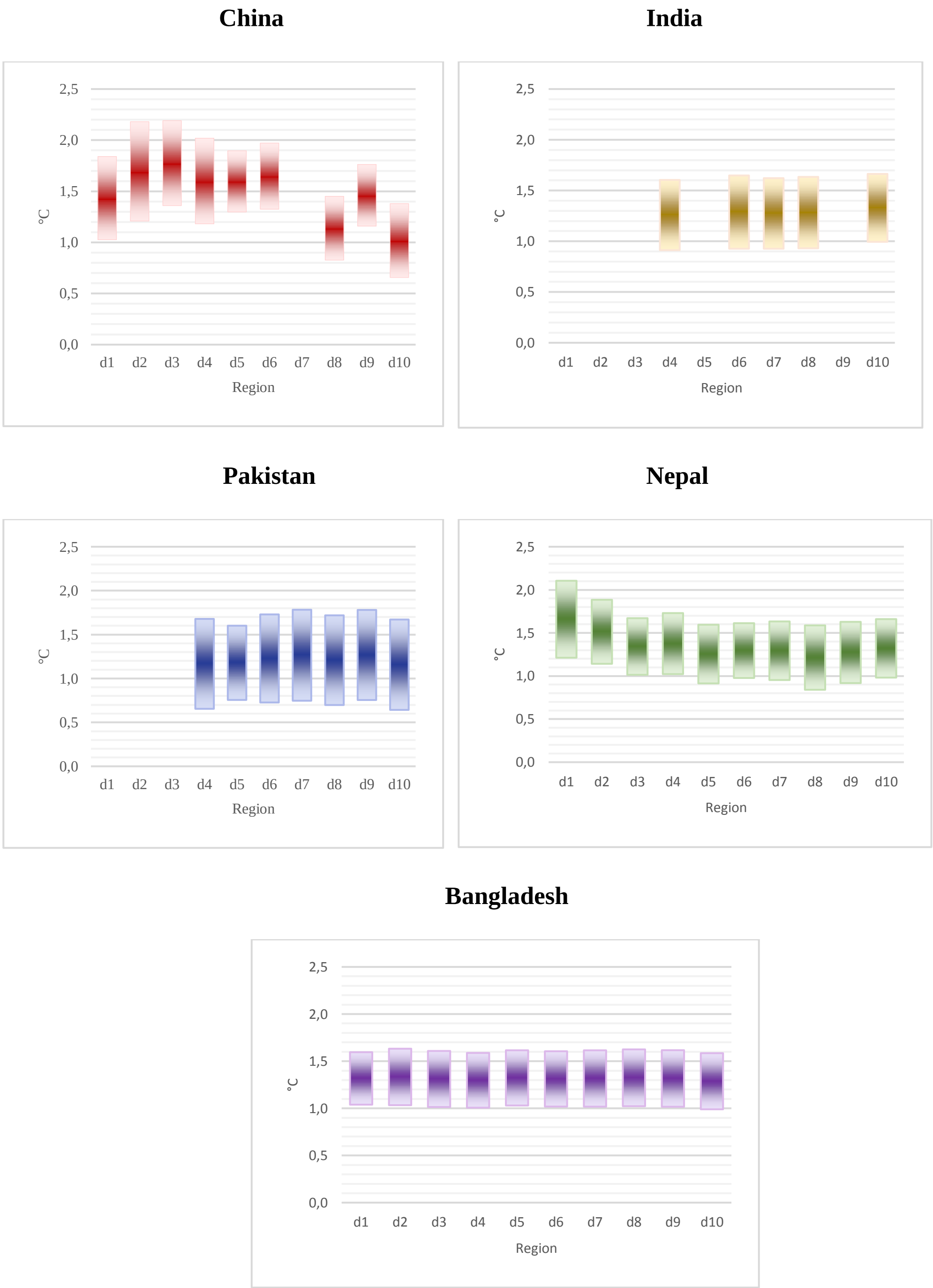


Figure 6. 90 percent confidence intervals for change in mean temperature 2011 – 2050 by country in regions with different population densities.

4 Economic consequences of climate change by country 2011 – 2050

What the economic consequences of the climate projections for Hindi-Kush Himalaya will be depend on many factors, and the economic analysis in this report addresses only some of them. Some constraints are due to the availability of data. The macroeconomic model is based on national accounts, which are not specified for Myanmar, Bhutan or Afghanistan in the GTAP database. These countries are, therefore, not included in this study. Moreover, Hindu-Kush Himalaya include only parts of China, India and Pakistan. National accounts data are provided only on national scales, meaning that we have to include the whole economies of these three countries. We are, therefore, unable to distinguish impacts and responses to climate change within the Hindu-Kush Himalayan regions of these countries from impacts and responses in the whole country. On the other hand, the downscaled climate projections are available only for the parts of these countries that comprise Hindu-Kush Himalaya. These projections were imposed on the entire country, meaning that we, in principle, analyse the economic consequences for China, India and Pakistan of projected climate change in the Himalayan regions of these countries.

An important aspect of the macroeconomic consequences is how climate change affect the terms of trade between countries. The version of the GRACE model used for this report divides the world into China, India, Pakistan, Nepal and Bangladesh while all other countries are aggregated into one region, called rest of the world (RoW). The economic projections thereby give a reasonable picture of changes in the terms of trade between these five countries in Hindu-Kush Himalaya, while changes in the terms of trade with other regions must be considered just as indications of the impacts on terms of trade with other countries. The climate projections for rest of the world reflect the annual averages for RCP8.5 in the underlying global projections. Here, the expected increase in mean temperature from 2010 to 2050 is nearly 1.5 °C, while there is no clear trend in the change in precipitation. The parameters in the impact functions for the rest of the world are calibrated from weighted averages of the impacts used to calibrate the impact functions in Aaheim et al. (2016).

Many other factors than climate change determine future social and economic development, and the impacts of climate change depend critically on how these factors develop. These relate, in particular, to population growth, technological improvements, and to how the income in each country are divided into consumption and investment. These may all vary across countries, and technological improvements will differ across sectors within countries. We use the long-term economic projections from the OECD (https://data.oecd.org/gdp/gdp-long-term-forecast.htm), published in 2015. They assume an annual rate of growth in population at -0.01 percent in China, 0.73 percent in India, 1.46 percent in Pakistan, 0.72 percent in Nepal, 0.70 percent in Bangladesh, and 0.84 percent in RoW. Economic growth for the world, measured by the sum of gross domestic products (GDP) is 3.0 percent per year up to 2050. The annual growth in China and India is 4.3 and 5.4 percent, respectively, giving an annual growth in the rest of the world of 2.3 percent. Pakistan, Nepal and Bangladesh are not specified in OECD's database, but we assume the average world rate of growth at 3.0 percent for these countries. The corresponding emissions follow RCP8.5, presented above.

The impacts of climate change are integrated in the model by a rate of change in the productivity of primary input factors or a rate of change in demand. Therefore, the economic consequences will depend on how the different sectors develop over time. Figure 7 shows the percentage change in each sector's share of contribution to GDP over the period 2010 to 2050 if there are no impacts of climate change. The sum of positive changes equals the sum of negative changes, and the length of each bar indicates the total change in the sector composites of the economies.

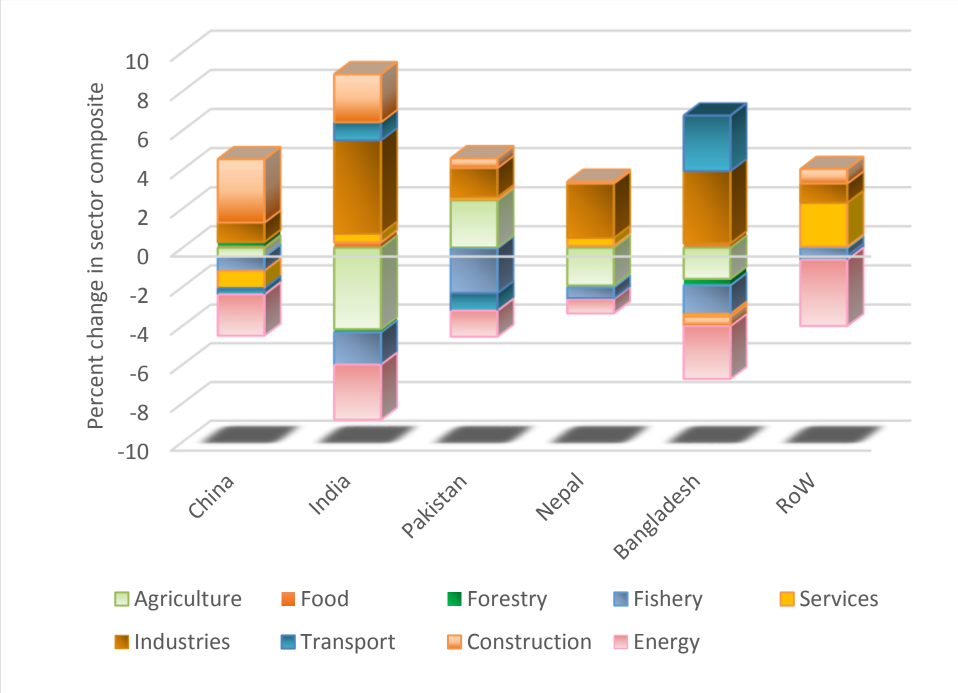


Figure 7. Percentage change in contributions to GDP by sector and country from 2011 to 2050 in the reference scenario

The largest change in sector composite takes place in India, and is partly due to a high economic growth. However, also Bangladesh goes through a substantial change, despite a considerably lower economic growth than China, where the composite of sectors changes moderately. Nepal is the most stable economy, when it comes to the sector composite. To some extent, the figure depicts a typical pattern of sector development under economic growth, with heavier contributions from service sectors and less from primary sectors. Fisheries decline in all regions, agriculture declines in all except Pakistan, and forestry declines in all countries except China. Energy sectors decline in all the countries, but less here than in RoW. This trend is related to a likely decline in resource rents. The increase in the contributions from the service sector is small in the Hindu-Kush region, however, and significantly lower than in RoW. On the other hand, the contributions from manufacturing industries increase substantially in all the Hindu-Kush Himalayan countries, while being moderate in RoW.

The economic projections thereby describe a period of industrialization in Hindu-Kush Himalaya, but rather moderate in Pakistan, Nepal, and Bangladesh. The growth in the building and construction sector in China and India indicates that the countries transform towards medium-rich countries. However, growth in GDP is due also to population growth in all countries except China, and to a broader integration of market activities in all countries. Economic growth is also expected to benefit people differently, meaning that poverty is likely to remain a challenge in all the countries.

Figure 8 shows the impacts of the climatic changes described in Section 4 on GDP. While GDP is not much affected in China, Pakistan and Nepal, the impacts in India and Bangladesh are significant. A reason why the impacts in China and Nepal are moderate is the relatively moderate direct impacts in the affected sectors, which are described by the impact functions, and for impacts in agriculture and health effects, in particular. Pakistan is characterized by a large food industry. While the contributions from agriculture to GDP is on the average for the Hindu-Kush Himalayan regions, the contributions from other sectors directly affected by GDP is low. Agriculture is strongly affected in Bangladesh and India, and the health effects in agriculture are stronger in these countries than in the other countries. The impacts of sea-level rise is also stronger in Bangladesh then in any other country, and the country has relatively large forestry and fishery sectors, which are sensitive to climate change.

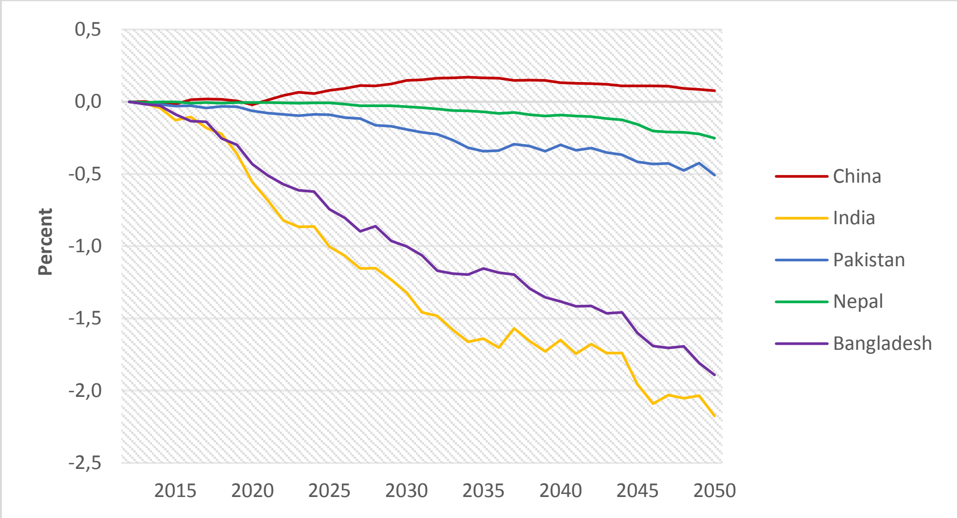


Figure 8. Impacts of climate change on GDP by country 2011 – 2050 under RCP8.5. Percent

However, these direct effects do not fully explain the impacts on economic activities. A change in the productivity of natural resources, damages to capital, health effects and changes in the demand for certain goods and services give rise to responses among economic agents with resulting market effects. As long as the impacts are relatively small, as in this case, there is a considerable room for adaptation, meaning that the market effects of the climate impacts are likely to be moderate. The market responses may both strengthen and weaken the impacts, depending on the shift in deliveries across sectors within countries and in the trade between the countries. Previous studies indicate, however, that the strong market effects, which give rise to major macroeconomic challenges under RCP8.5, appear after 2050 (Aaheim et al., 2016a).

Figure 9 shows the influence of the market mechanisms on GDP in this study. Here, the direct effects on the different economic activities, described by the impacts functions in Annex 1, of the climatic changes in 2050 are summed up and compared with the projected GDP from the model in 2050. Except for Pakistan, the market effects are small in absolute terms, although large in relative terms in China and Nepal. In India and Nepal, market effects contribute to worsen the impacts. In Nepal, market responses turn positive direct effects to a negative economic consequence. The opposite is the case in China, but here, the total impacts are very small, indeed. Bangladesh also benefits from market responses, although the market effects are moderate, as expected.

The projected market responses in China, India, Nepal and Bangladesh confirm earlier findings, which indicate that despite significant adaptation among economic agents, the effect on GDP may not differ much from the direct effects under moderate climatic changes. This reflects the fact that the main part of the economic impacts relate to the productivity of the primary production factors, natural resources, capital and labour, which leads to an increase in prices, but with limited opportunities to increase the supply.

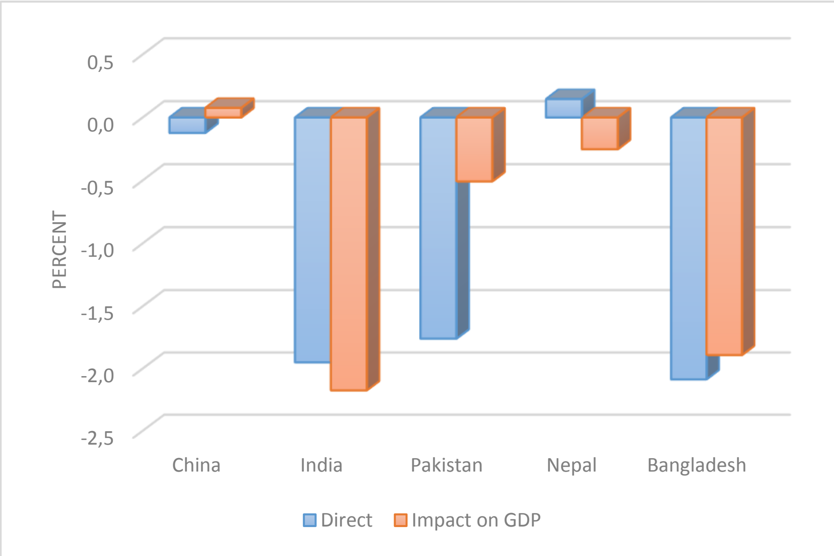


Figure 9. Direct impacts and projected impacts of climate change by country on GDP in 2050

However, there may be exceptions, and this is illustrated by the difference between the direct and the projected impacts on GDP in Pakistan. Here, the direct effect of the climatic changes constitutes 1.75 percent of GDP in 2050, but due to market effects, this is reduced to 0.5 percent. One explanation is the importance of the food industry in Pakistan, which contributes between 15 and 20 percent of GDP, and eight to ten times the contribution if this sector in the other countries. At the same time, the contribution from agriculture, which is far more vulnerable to climate change than the food industry, is on the average for the region. Climate change gives a significant increase in prices for food products in Pakistan, and this explains at least some of the difference between the direct effect and the impact on GDP in Figure 9.

The different vulnerabilities in agriculture and in the food industry are due to the broader opportunities for adaptation in the food industry. Climate change may affect the capital stock, the availability of labour and other input factors, but all of them may be compensated to some extent, in particular if the price of food increases. These opportunities are more restricted in agriculture, because of its dependency on the utilization of particular land areas, which are directly affected by climate change. Thus, a reduction in deliveries to the food industry from agriculture may be compensated by increasing imports of raw materials, while the output in domestic agriculture is constrained by the productivity on available land areas.

The economic consequences of climate change in a country are thereby related to its relationship with other countries through trade. How closely depends partly on the opportunities to compensate negative effects in own country with imports from other countries, and partly on how export opportunities change because of impacts in other countries. This is indicated by the impact of climate change on international trade, displayed in Figure 10, which shows how the net value of trade (exports minus imports) is affected in 2050, measured in US$ per 1000 US$ value added. The pattern is similar to the pattern of the impacts on GDP. The consequences for China and Nepal are small, but both countries improve their terms of trade. The effect on international trade in the food sector in Pakistan, discussed above, is also negative. The impact is, however, moderate in relative terms, while large in absolute terms, which illustrates the adaptation in this sector in Pakistan. The strong negative impacts in India and Bangladesh leads to a clear worsening also in the balance of trade with other countries and regions.

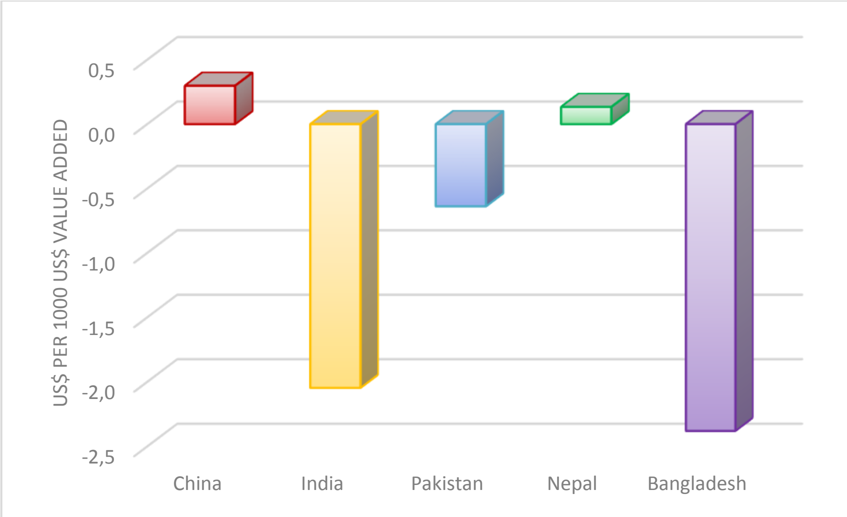


Figure 10. Impact of climate change on trade (export minus import) in 2050 by country.

The impacts of climate change on total consumption differs from the impacts on GDP for most of the countries in this study. In Bangladesh and India, the negative impacts on consumption are about half the impact on GDP over the whole period, and the impacts on consumption is approximately 2/3 of the impacts on GDP in Pakistan. Nepal is the only country where the impacts on GDP and on total consumption are about the same. In China, the positive impacts of climate change on GDP turns negative if using total consumption to indicate climate impacts, although only by -1 percent in 2050. What this shows, however, is that a broad evaluation of the socioeconomic impacts of climate change is not only a question of getting to know how economic activities are affected, but also how to measure the impacts.

For the countries addressed in this study, and for developing countries in general, a more critical question is how relevant indicators provided by the national accounts are for evaluations of how climate change will affect the people. From the national accounts, the contributions to GDP from agriculture is between 8 (China) and 30 (Nepal) percent, and the shares remain more or less stable throughout the period 2011 – 2050. It is difficult to obtain comparable numbers for people whose livelihood relates mainly to agriculture in Hindu-Kush Himalaya. Maikhuri et al. (2015) state that agriculture is the major livelihood activity for over 70 percent of the inhabitants of the Himalayan region, but it is not clear whether this applies to the Himalayan region of India, or to the whole Himalayan region. The National Sample Census of Agriculture reports that 78 percent of the Nepalese population were engaged in agriculture in 2011, and 77 percent of them live on farms less than 1 ha. According to Wikipedia, 300 millions in China, or more than 25 percent of the population works in the agricultural sector, but the share is probably higher in the Himalayan region.

Despite the uncertainties about how many people are engaged in agriculture, the contributions to GDP from agriculture is clearly an inappropriate indicator of how important agriculture is for the welfare of people in the Himalayan region. The impact on the sector’s contribution to GDP is therefore a poor indicator of the welfare effect of climate change to people whose livelihood depends on agriculture. On the other hand, impacts on national economic indicators signalize consequences of climate change that may be important to all farmers. The next two sections therefore addresses how the combination of climatic changes and the resulting impacts on the macroeconomic drivers may affect farmers in the Hindu-Kush Himalaya. The results are based on a survey of 60 households in Bamrang Khola.

5 Farming in Bamrang Khola in the district of Khotang, Nepal

Khotang district is one of seventy-five districts in Nepal, in Eastern Development Region in the Koshi basin. Its western boarder is 120 – 130 kilometres east of Kathmandu (see Figure 3). The district covers an area of 1591 square kilometres, with more than 80 percent between 300 and 2000 meters. It is classified as upper tropical and sub-tropical zones. Agricultural land covers nearly 50 percent of the area. Most of the remaining area is covered by forests and underbrush.

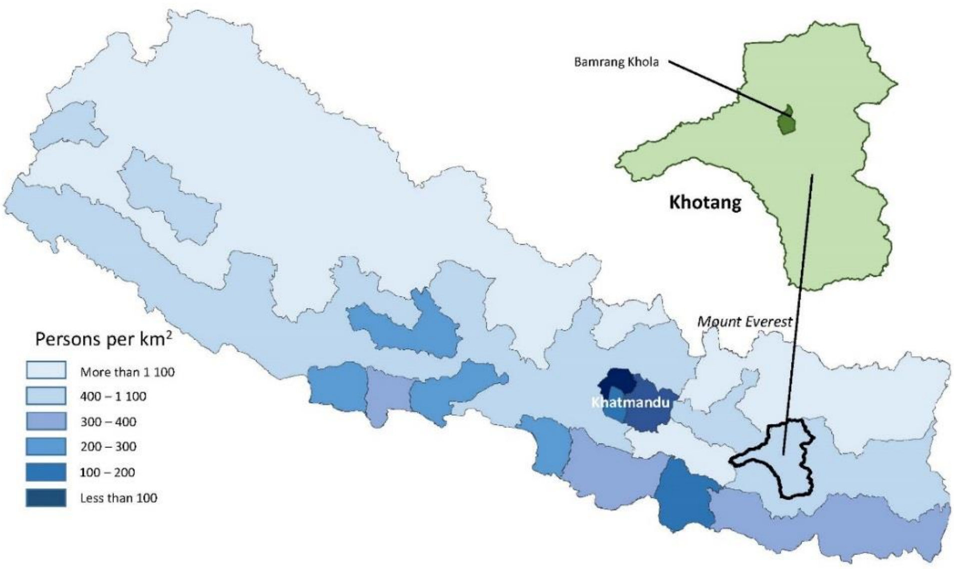


Figure 11. Bamrang Khola, Khotang and population densities by district in Nepal

The population in Khotang in 2011 was slightly above 206 000, after having declined from about 240 000 in 2001. Agriculture and forestry are by far the most important sources of income and subsistence in the district, and contribute to nearly 2/3 of the estimated GDP in Khotang. This is twice the average contribution to GDP from agriculture in Nepal. The main cultivated crops are paddy, maize, wheat, millet and potato, all of which are typically grown for subsistence. Cash crops, such as sugarcane, tea, coffee and tobacco are grown in some places.

5.1 Smallholder farming in Bamrang Khola

The 60 farms covered by the survey range from 0.075 to 2.25 hectares, with an average of 0.76 hectares. The land is divided in to rain-fed land, which covers 0.31 hectares on average, and irrigated land, which covers 0.45 hectares on average. 7 small farms, with an average size of 0.30 hectares, have no irrigated land. 35 percent of the farms are less than 0.5 hectares, and 47 percent are between 0.5 and 1.0 hectares. Different crops are grown on the different types of land. Millet is grown entirely on rain-fed land, while irrigated land is needed to grow paddy and wheat. Maize and potato are grown on both types of land. The share of irrigated land tend to increase as farms become larger.

The survey covers rather typical farm sizes in the district of Khotang, where 80 percent of the farms are less than 2 hectares. The remaining 20 percent of farms in Khotang are more or less equally distributed between 2 and 10 hectares, and 2.5 percent of the farms are larger than 10 hectares.

The main crops on the farms in the survey are paddy, maize, wheat, potato and millet. Only a few other crops are grown, such as soya beans, on 13 percent of the farms. All the farms in the survey keep livestock, mainly cattle and goats. 15 percent keep other livestock, most of them hens, and some pigs. The production of crops and livestock differ considerably across farms. Figure 12 and Figure 13 show the range and the averages of the different products on the farms. The numbers in parentheses show the number of farms that reported production of the respective crops.

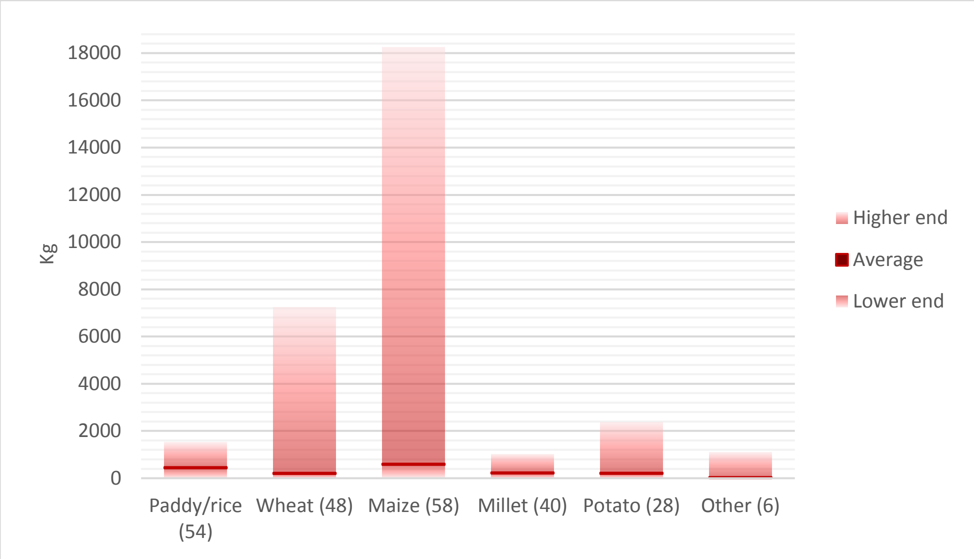


Figure 12. Averages and ranges of the production of different crops per farm per year. Kg

None of the crops is grown on all farms, but only 2 of the 60 farms do not grow maize, and 6 farms do not grow paddy/rice. Figure 4 shows that the range of production of each crop at the different farms. The dark line is the average. The range of all crops is much larger than indicated by the range of farm sizes, mainly because a few farms specialize in production of one or two crops. This applies in particular for wheat and maize, where the average production is about 3 percent of the maximum production. Paddy/rice is the most equally distributed crop, and the distribution of production corresponds well with the distribution of farm sizes.

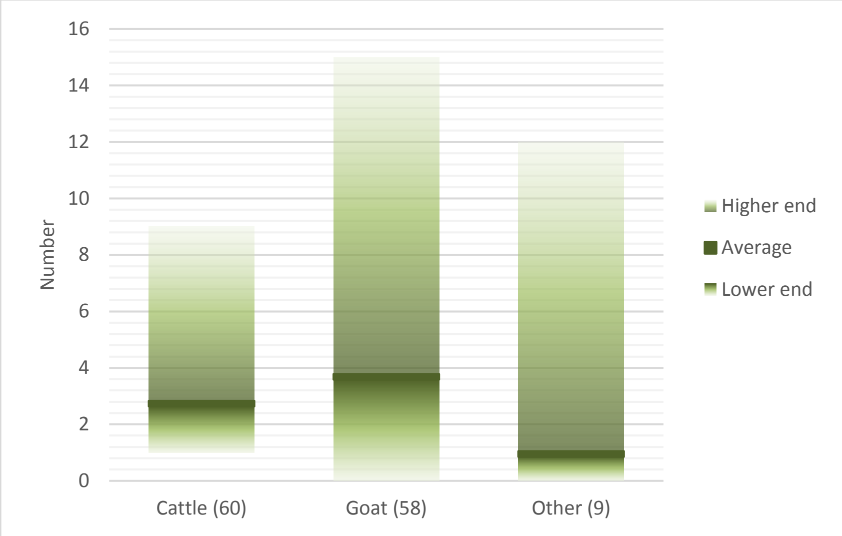


Figure 13. Averages and ranges of livestock per farm. Number of animals.

Figure 13 shows the distribution of the number of livestock. All farms have one cattle or more, with an average of 2.7. Nearly all farms have goats, with an average of 3.7. Both cattle and goats are distributed similarly to the distribution of farm sizes. 9 farms keep other livestock. These cover different species, which explains why the number of other animals is broadly distributed.

Despite the similarities in the distribution of farm sizes and the distributions of some crops and livestock, it is not possible to draw clear conclusions about the composite of products on a farm with reference to its size. Except for potatoes, there is no correspondence between the production of crops or the livestock and size of farms. The same applies for correspondences between crops and livestock and the distribution of rain-fed and irrigated land. For potatoes, one may say that production increases with farm size, while it tends to be reduced by an increase in the share of irrigated land.

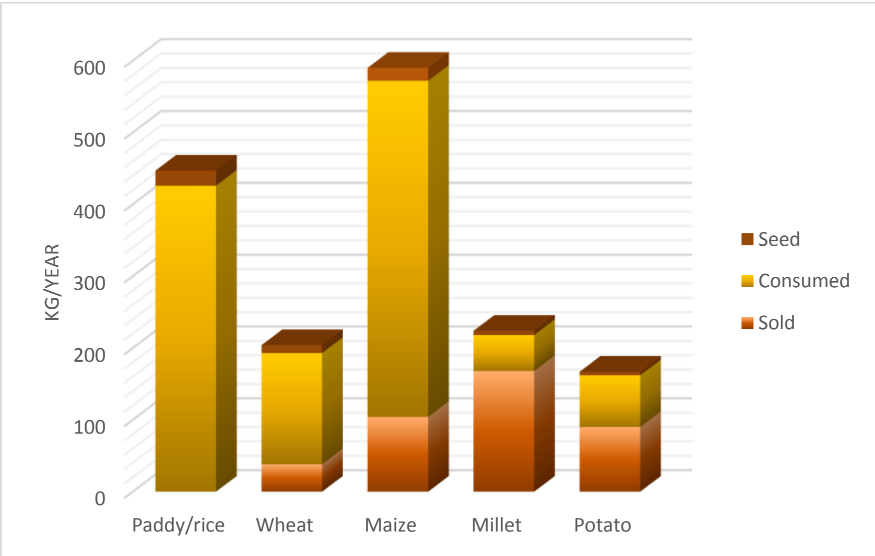


Figure 14. Average usage of crops produced on surveyed farms. Kg per year.

The broad distribution of the production of some crops can partly be explained by the usage of the different crops, which is displayed in Figure 14. The second most important crop, paddy/rice, is grown entirely for consumption on the farm. An equally large amount of maize, which is the most important crop when measured by the weight, is produced for consumption on the farm, but nearly 20 percent of the total production is sold. Maize and wheat are sources of income at some farms, from which a relatively large amount is sold. The monetary income from crops is in most cases from sales of potatoes and millet. Between 3 and 5 percent of the output of crops is used as seed.

Income from sales of agricultural products constitutes nearly 1/3 of the total income to the farmers covered by the survey. 60 percent of the cash income from agricultural products is from the sale of crops, and 40 percent is from selling livestock and related products. Despite the relatively moderate share of monetary income from farming activities to the total monetary income, there is a close relationship between the two, even though some households with a low income from agriculture have a relatively high total income. The trend that appears from a simple linear regression indicates that a household that earns one rupee more from selling agricultural products than another household earns between 0.1 and 0.5 rupee more from other sources or activities.

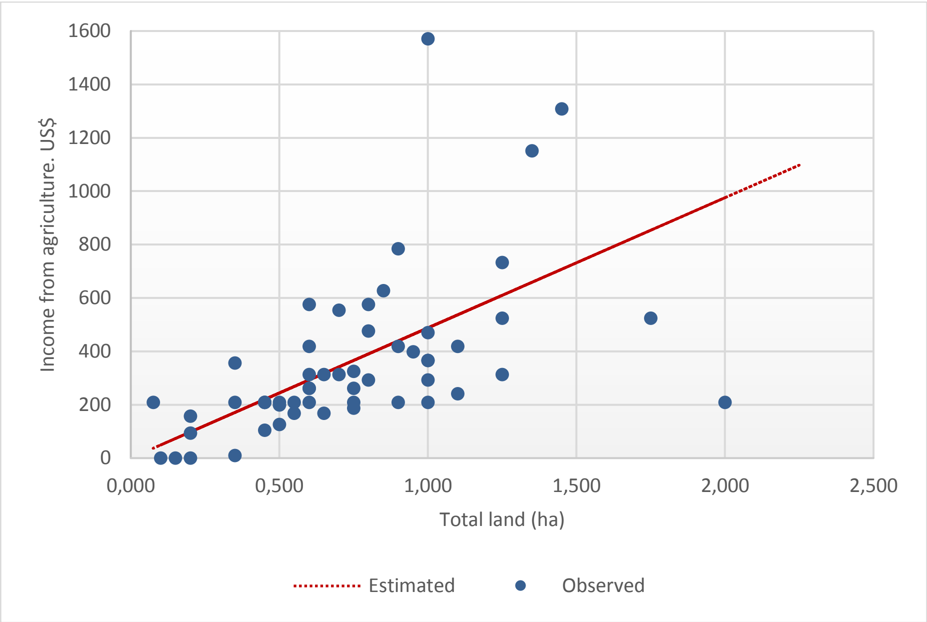


Figure 15. Observed and estimated monetary income from sales of agricultural products by farm size. US$.

While it is difficult to link the production of the different crops and the livestock to the size of farms, the income from agriculture is clearly related to it. Figure 15 shows the observed income from agricultural products at farms of different size and the corresponding estimated income from a simple linear regression. One outlier with very high income is excluded from the figure. The size of a farm explains 72 percent of the sales income from agricultural products ($R^2 = 0.72$).

The monetary income thereby increases by farm size, both from activities on the farm and from activities outside the farm. This confirms a presumption that farmers get more involved in market transactions the larger the farm, but suggests that farms covered by this survey are not sufficiently large to keep families busy all the time. This gives a room for spending time on work outside the farm.

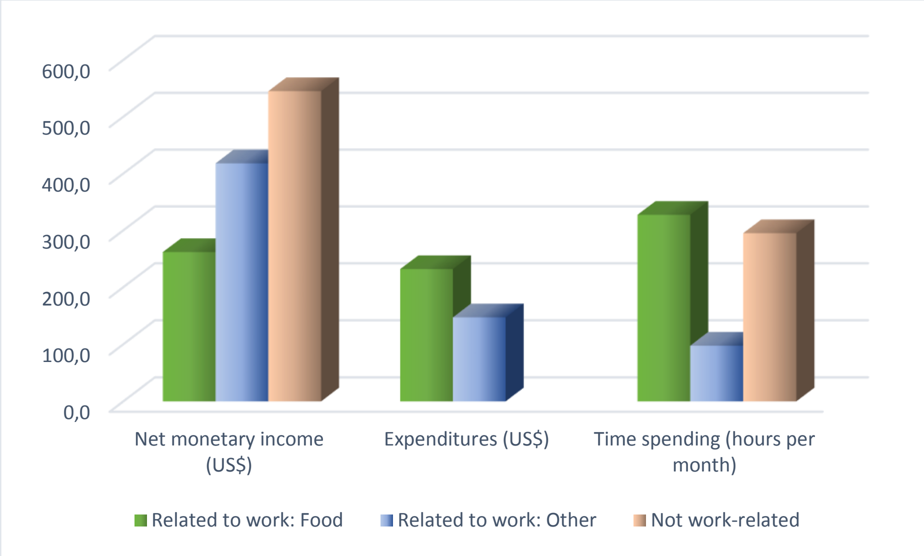


Figure 16. Sources of income, expenditures and spending of time related to farming activities and other activities

Figure 16 summarizes the findings of relevance for the microeconomic modelling from the survey, and shows the economic balances and allocation of time in the household from the survey. The table divides work and spending of time into those related to the production of food, those related to other work and those not related to work, while expenditures are divided into purchases of food and purchases of other goods. Most of the monetary income is not related to work, and consists primarily of remittances. The survey does not divide remittances further into sources, but they are most likely transfers from family members who work in other places and countries. The second most important source of income is from work or businesses outside the farm. However, the time spent on working on the farm is three times higher than working outside the farm, which illustrates the degree of subsistence among the farmers in this survey. 60 percent of the households' expenditures is spent on food not produced at the farm. This shows the importance of addressing possible impacts of climate change for the smallholders, as they run the risk of getting a lower productivity on their own farm, and at the same time get higher expenditures for the food they have to buy.

The distributions of income, expenditures and time vary significantly across farms. An apparent difference occurs between farms led by men and farms led by women. Despite slightly larger farms, the income from the sales of products from the nine farms led by women is only about 2/3 of the average income, while the income from other activities and other income is twice as high as the average. The families on women led farms spend equally much time on work on the farms as on other farms, but they spend about 30 percent more time on work outside the farm.

An explanation to these differences may be that the man on the farm moves to other places to get a job, and sends money back to the family at the farm, which is led by the woman. This is probably a more likely explanation than a possible difference in prioritizing monetary income between men and women, which is sometimes assumed, but seldom confirmed. Still, an unexpected finding here is the high monetary income from work outside the farm on farms led by women, particularly when compared with a relatively little extra time spent on earning this income.

A comparison between monetary income and expenditures across farms indicates the poverty among farmers in this survey. 21 farms ran with a deficit ranging from 4 to 513 US$ in the year the survey was done (2014). With one exception, all these farms were less than 1 hectare, with an average size of 0.72 hectares.

5.2 Transformation of the results from the survey to the modelling

The microeconomic model takes the total output from all farms in a community, a region or a country as its point of departure, and divides total area of land, production, work, income and purchases into single farms of different size. To feed the model with results from the survey, we use the totals for all sixty farms from the survey, and leave to the model to allocate the totals on farms of different size under the assumption that all farmers would make exactly the same choices if the size of their farms were equally large. The model thereby explains how production, consumption and division of work change for the typical, or representative, smallholder family with access to different land areas.

The results from the survey are reported in different units, depending on how they are usually measured. The model applies values and distinguishes prices and quantities, but do not separate between measures of different quantities as long as the quantities used are relevant for the decisions taken in the households. The problem in finding a relevant measure for quantities was illustrated by the problem in finding a relationship between the size of farms and the production of different crops and livestock. However, a look at the income from the production on the farm made it clear that there is a correspondence between farm size and the output quantity. The question is, then, how to find a relevant measure for the quantities reported in the survey for the model.

We follow the usual approach in economic analyses, where all physical units are replaced by a measure for quantities that refers to its economic importance, and expressed in monetary terms. The advantage of such a measure is its relevance for economic evaluations. The disadvantage is that these units in most cases consist of aggregates of commodities or services with different qualities. If the aggregate changes, the composite may change, meaning that the quality of the aggregate will change, which is not reflected by the economic analysis. For example, a doubling of the quantity of maize and rice produced on a farm may not be to double the output of both, but to put more weight on one of them, which implies a change in the quality of one unit of the aggregate.

Here, all physical units were transformed to aggregates measured in 1000 US$, by the following procedure:

- Production of crops are reported in physical weights, and livestock is reported in numbers. We use the weights of crops (kilos) directly to measure aggregate output of crops, and add weights of livestock by assumptions on annual unit weight of each livestock. Note that these assumptions may not be not critical, as long as we know what is measured. To limit the bias from a change within the aggregate, one should choose composites expected to be insensitive to changes.
- Total production is divided into a consumed amount, a sold amount and an amount of seed from the totals in the survey. The resulting physical quantities were then converted to quantities in US$ by dividing the income from selling products from the farm, net of the cost of input, with the physical quantity net of seed. This gave a conversion factor of 0.88 US$ per ton output.
- Multiplying the tons of total output from the farms with this factor gives the quantity of total output, measured in US$, which is 95 900 US$ for the 60 farms. In the model, this is interpreted as the sum of input of labour and input of land.
- Similar to the quantity of crops, the quantity of labour is estimated on the basis of income and time spent on work outside the farm. On average, the time spent on work on the farm is 13.6 days per month, while 4.1 days per month is spent on work elsewhere or business activities. This gives an average income of 418 US$ per farm. Then 12.6 days are free or spent on trying to get other work. Roughly, assume that two days per week are free, plus one extra day per month. Then, 9.6 days are free

each month, and 2.7 days are spent on search. We include search in the days spent on work off the farm. Then, the average daily income for work off farm is 5.1 US$.

- Daily income from work off the farm is used to divide work on and work off the farm. It implies that total availability of work in the 60 households is 75 500 US$, which is divided into 50 400 US$ spent on work on the farm and 25 100 US$ on work off the farm. This defines the total availability on all farms, regardless of size, and the division of work on the average farm.
- The input of land is the difference between the output and the input of labour, which amounts to 45 500 US$. The 60 farms cover a total area 48.35 ha, meaning that one hectare of land corresponds to 941 US$.

This completes the transformation of data from the survey to the model. Since quantities are measured in US$, all prices are equal to 1 from the outset. The model needs further input on a nutrition constraint and taxes, which will be discussed in each case below.

To interpret the results and derive possible implications for communities and for societies, it is useful to represent the distribution of farms by a distribution function. For this purpose, we use a lognormal distribution with expectation and standard deviation of farm size taken from the survey. Figure 17 shows the observed and estimated distributions.

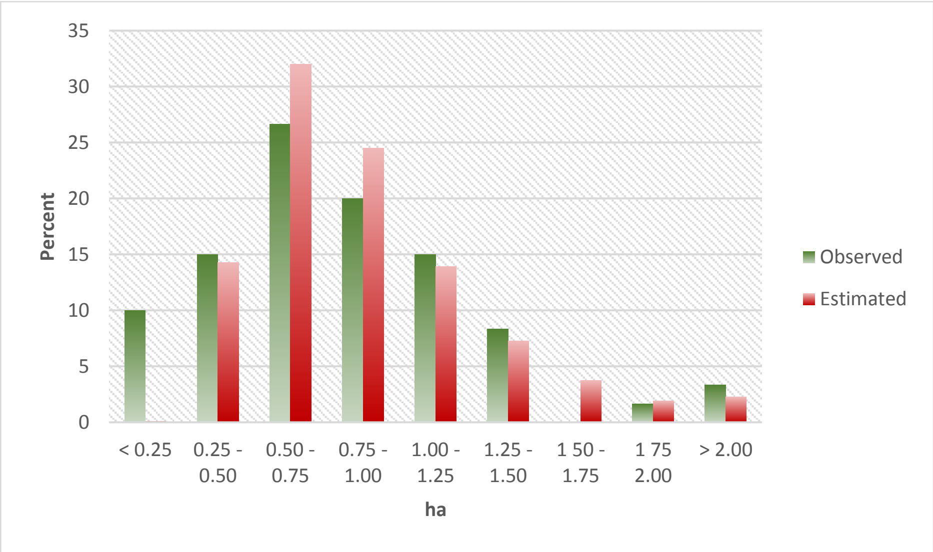


Figure 17. Observed and estimated distribution of farm sizes

The estimated distribution is somewhat narrower than the observed distribution, with less very small farms below 0.25 ha, but more farms 0.25 and 1.0 ha. There are also more farms larger than 2.0 ha in the survey than indicated by the theoretical distribution.

6 Challenges to smallholders under climate change

The calibration of the model refers to averages of the farms. Therefore, the averages for the variables from the calibrated model will not exactly match the observed averages. Figure 18 shows the observed averages, the results from the model on a farm with average farm size (0.7 ha) and the averages from the model using the farm distribution in Figure 17.

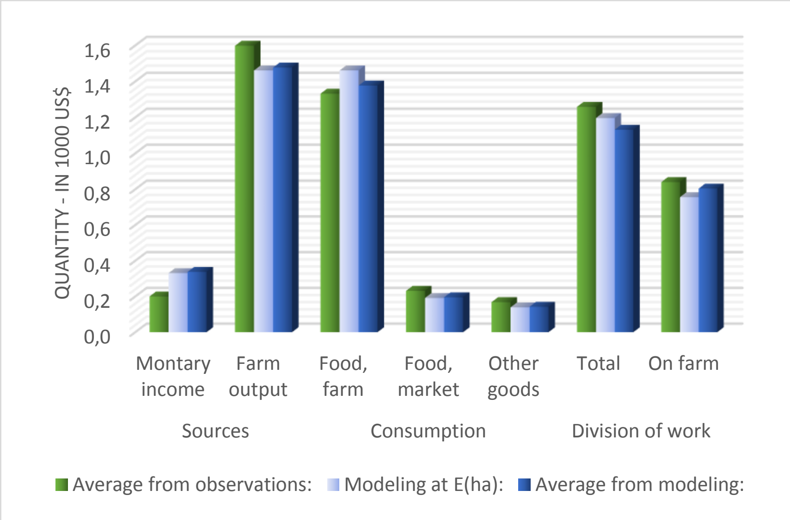


Figure 18. Observed and calibrated results of the main averages for variables from the model

With the exception of monetary income and consumption of food from the farm, the results from the modelling is slightly lower than the observed values. For the calibrated average farm, this is explained by the skewed distribution of farms, while the average for calibrated farms are likely to be lower because of the overrepresentation of small farms in the estimated farm distribution, shown in Figure 9. The only big difference is the calibration of monetary income, which is 1/3 as high in the calibrated model as in the observations. The explanation is simplifications in the model, which will be discussed below.

Figure 18 shows monetary income and consumption at farms of different size estimated by the model. The farms can be divided into four groups. The first group consists of families whose total food consumption is below a critical limit to feed the family, or the nutrition constraint. This is where the sum of food from farm and food from market consumption is below a certain limit. To illustrate, assume that this constraint is set to 1 000 US$ per year. Then, families at farms below 0.35 ha are unable to feed themselves.

The second group consists of families who consume enough food to avoid starvation, but consume all the food they produce on the farm themselves, because the farm is too small to allow anything to be sold, called the output constraint. These families cover farms between 0.35 and 0.7 ha, that is, close to the average farm size in Bamrang Khola. Farms above 0.7 ha do not meet the output constraint, but for farms between 0.7 and 0.85 ha, there is a third group, whose benefit from selling products do not correspond to the value of consuming them, because of transaction costs. In Figure 19, it is assumed that these farms consume everything they produce, and that selling products takes place at farms that are able to cover all the transaction costs. At 0.85 ha, work off the farm therefore “jumps” downwards, and consumption “jumps” upwards, which illustrates the benefit of reallocating work from outside the farm to the farm.

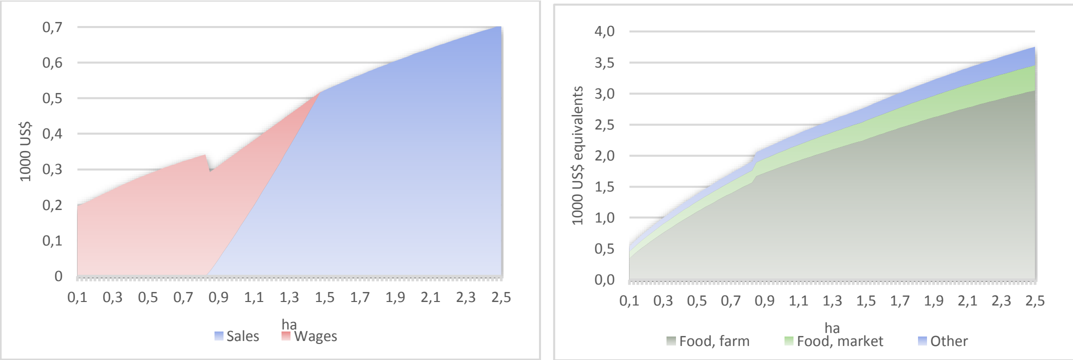


Figure 19. Sources of livelihood and consumption pattern at farms of different size. 1000US$

The fourth group consists of families who do not meet any of the constraints. They work on the farm to produce what is possible, and work outside the farm if they have time left. However, for farms above 1.5 ha, all their time is spent on the farm. In principle, these families may employ people to further increase the output. However, they will have to pay full wage, as opposed to wage they expect to gain by working outside the farm, which does not compensate for unpaid time spent on search and other uncertainties. For farm sizes below 2.5 ha, it is not beneficial to employ any workers outside the family, according to this model.

Note that the model aims to explain activities and consumption representative for all the households in the survey, but placed on farms of different size. Differences between the results and an observed household may be due both to simplifications in the model, and to differences between the addressed farm and the family living there and the representative household.

To illustrate the impacts of climate change, we consider two cases. In the first, we impose the projected average climatic changes for Nepal on the impact functions for the productivity of land and on the productivity of workers in agriculture from the macroeconomic analysis, and add the impacts on food prices from the macroeconomic model. In the second, we replace the projections of average climatic changes in Nepal with the downscaled climate projections for areas near Bamrang Khola, but include the impacts on prices as in the first case. We thereby assess the impacts in two communities equal to Bamrang Khola in 2050, where national impacts (on prices) are the same, but the climatic changes differ

6.1 Impacts of climate change as described by the macroeconomic analysis

The climate projections for Nepal in 2050 gave an increase in temperature at 1.5 °C and 1 percent reduction in annual precipitation. According to the impact functions, the productivity of land is thereby reduced by 2.7 percent, and the productivity of labour is reduced by 2.4 percent. That is, the impacts are clearly negative, although moderate. This is in accordance with previous studies (Aaheim et al., 2017), which indicate that the impacts of climate change on a macro scale are not likely to be dramatic before 2050, and that severe impacts may be avoided if the temperature increase is limited to 1.5 °C.

The microeconomic model gives rather limited impacts also on the micro level. If the effects on the productivity of land and on work related to effects on health are considered without price effects, all the variables on monetary income and consumption are reduced between 2.4 and 2.7 percent for all groups, irrespective of what the constraints are. This is because the productivity of land and the productivity of labour are affected nearly by the same rate, and together they represent the flexibility farmers have to adapt. Apart from the shift of scale, there is little to gain by changing the relative spending of time on work on farm and outside farm, meaning that the consumption pattern also will remain as before, but on a lower level. The only notable change that might occur is that some farms encounter new constraints, but the impacts are too small to conclude that this is likely to happen. As a result, there is a limited potential for adaptation in this case.

It is worth to note that most studies of impacts of climate change on agriculture highlight effects on the productivity of land without attention to other effects, and that studies of adaptation address what farmers can do to limit the consequences of effects on the yield. If we do so in this study, we find it beneficial for farmers to change their allocation of time, sources of income and consumption patterns. Moreover, the most useful changes to adapt to a lower productivity of land will differ depending on what constraints the farming households are subject to.

Figure 20 shows the percentage change in the indicators for households on the different groups of farms. The allocation of time, income and consumption differs notably from the former case, where climate change affects the productivity of land and labour productivity equally. Monetary income and the consumption of food from farm are clearly reduced on all farms. The reduction corresponds more or less with the reduction in total productivity. This amounts to approximately half of the reduction in the productivity of land. The second half of the production is related to labour, which is unaffected in this case. Monetary income is reduced more on constrained farms than on unconstrained farms, while the opposite is the case for the consumption of food from farm.

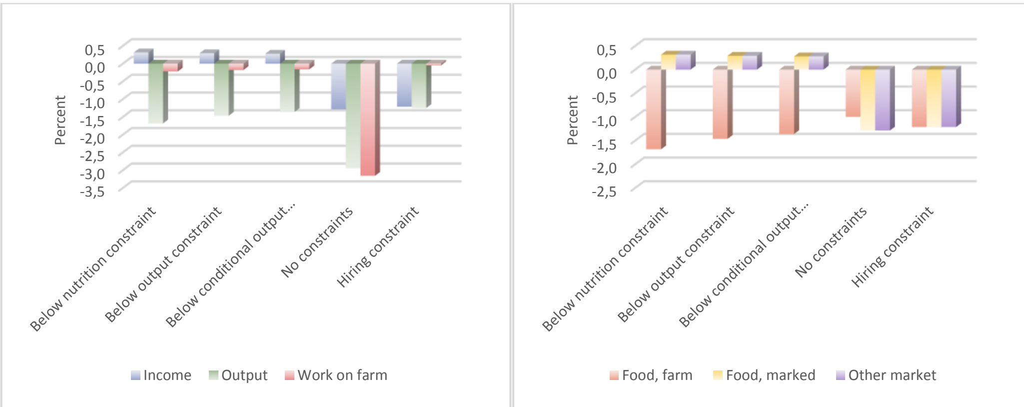


Figure 20. Changes in sources of livelihood and consumption patterns with effects on the productivity of land only, by group. Percent.

Households that in some way are subject to the output constraint, that is, farms below 0.85 ha, respond by less work on the farm and more outside farm. This means that more of their consumption is based on buying goods in the markets. For larger farms, both monetary income and output is reduced, but less on farms subject to the hiring constraint than on farms without any constraints. For the latter group, work on the farm remains as before, because they spend all their time on the farm. At unconstrained farms, work on the farm is reduced quite significantly. This is because they have an opportunity to substitute consumption of food from the farm with market-based consumption, which limit the welfare loss of the climate impact. This is not an option at farms subject to a hiring constraint.

The conditions that the farmers covered by the survey are living under, shows their dependency on the productivity within the family and its farm. A relatively small part of their livelihood depends on economic transactions, although some of these transactions may be essential to their welfare. Next, we add the market effects indicated by the macroeconomic projections to get the full picture of the impacts of climate change to smallholders. Because of the relatively small scale of impacts that affect the families directly, the market effects are also moderate. In Nepal, the price of agricultural products sold increases by 0.4 percent, while the price of food increases by 0.3 percent. The price of other goods increases by 0.1 percent, and wages decrease by 0.2 percent. These relatively small effects must be considered in the light of the small physical impacts, although some characteristics are worth mentioning.

One is the difference between farms subject to one of the constraints addressed above, and the 25 percent of farms without any constraint. Figure 21 shows how the price effects add to the impacts on the different variables when climate change affects both the productivity of land and health. The numbers in the figure thereby add to the negative impacts between 2.4 and 2.7 percent on all the variables. Farms without constraints take full advantage of higher prices on agricultural products and lower wages. Therefore, they work more on the farm. The added output can be sold in markets, and therefore, they take advantage of the higher prices on food as well. This limits the loss resulting from lower wages. The market effects therefore benefits households on these farms, and implies that the food consumed from the farm can be sustained. However, their total income increases, and so do the consumption of food from market and of other goods.

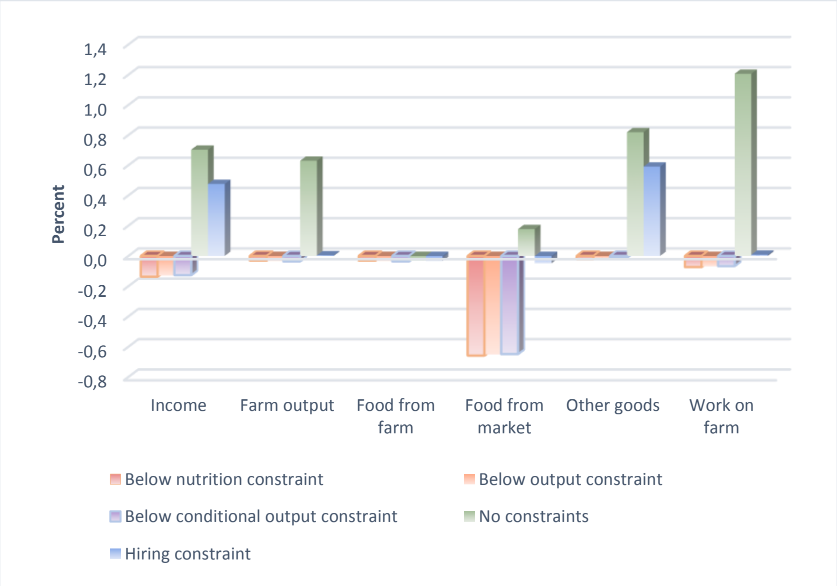


Figure 21. Changes in sources of livelihood and consumption due to market effects alone when climate change affects the productivity of land and health. Percent

The price effects are beneficial also to farms subject to a hiring constraint, which applies to 5 percent of the farms, but they benefit less than households at unconstrained farms. The reason is that it is not beneficial to hire people on these farms, but they do not benefit from shifting their source of income either, as all their time is spent on the farm. Hence, their consumption of food is hardly affected, while the consumption of other market goods increase because the price of these goods are lowered compared to the price of food.

The market effects to the remaining 65 percent of farms clearly contribute to lower welfare, primarily because of a lower income from work outside the farm. This means that they can buy less goods in the market. As food prices increase more than other prices, nearly all of the reduction in market consumption is drawn from the consumption of food. It may be noted that despite the reduction in wages, the work on farm is also reduced a little. This is explained by the output constraint, which means that the change in relative prices between food and other goods implies a relative higher appreciation of non-food goods, which can be achieved only by monetary income at these farms. The only way to earn this money is to work more outside the farm.

Because of the small scale on the impacts, there is no big change in the number of farms belonging to groups subject to the different constraints, but market effects contribute to a slight slack of the constraints by approximately 5 percent of the farms. 2.8 percent of the farms shift from being subject to an output constraint to a conditional output constraint, and 2.2 percent enters the group without constraints. Less than 0.5 percent enters the group with a hiring constraint. Despite the negative impacts of climate change in general, the market effects contribute to less constrained activities on a few farms.

6.2 Impacts of climate change on the local level

The previous section imposes impacts expected to hit the agricultural sector in the Nepalese economy based on information on general climate indicators for Nepal on a community, where relatively few farmers are fully integrated in the economy. On the local level, the climatic changes as well as their impacts may differ considerably from these national aggregates. To get a better picture of the consequences on a local scale, one may instead utilize information from specific communities on the expected climatic changes, and their impacts. In this section, we draw on the downscaled projections in subdomain 7b in van Oort (2014) to address local impacts and the challenges that the households may face. Subdomain 7b covers the mid-hills of Koshi basin in East Nepal, and includes a small part of northern Khotang. Bamrang Khola is not included in this subdomain, but its altitude corresponds better with the average altitude of Bamrang Khola, around 2 000 meters, that subdomain 7c, Terai, where Bamrang Khola is situated.

The modelling approach to a study of local conditions presented in this report could be improved by drawing on insights from qualitative studies of adaptive capacity in Nepal. This is not done here, for two reasons. First, the adaptive capacity of farmers in Bamrang Khola was not studied in HICAP beyond the survey presented in Section 5. Second, and more important, the approaches used in the studies of adaptive capacity (Aase, 2017a) are not fully compatible with the assumptions underlying the microeconomic model used here. In synthesising the information from the 60 farms in Bamrang Khola, we use the totals and the averages, which correspond to the comparative approach discussed in Aase et al. (2017), while the ethnographic studies are based on a cumulative approach. The difference can be explained by the different aims of the studies. Economic studies derives farmers' choices from the assumption that they maximize their utility, while the focus of ethnographic studies is rather to explore farmer's motivations from analysing the choices they make.

However, a main purpose of the ethnographic studies is to explore the flexibility of farming, and to show the opportunities and barriers to make changes under given climatic changes. The economic study is based on definitions of flexibility within a certain scope defined by the model, which are tested with observed data. They are based on general assumptions here, however. The flexibility was illustrated by the comparisons between the production of the different crops and farm sizes, where no correspondence could be found, and the comparison of income and farm size, which was clearly related. The transformation of crop yields to an aggregated output from the farms, measured in US$, in the economic study thus reflects some of the flexibility of alternation in the ethnographic studies (Aase, 2017b). In principle, the flexibility of retention in ethnographic studies may also be reflected in the modelling of the decision-making in the economic analysis, but this is not made explicit in this report.

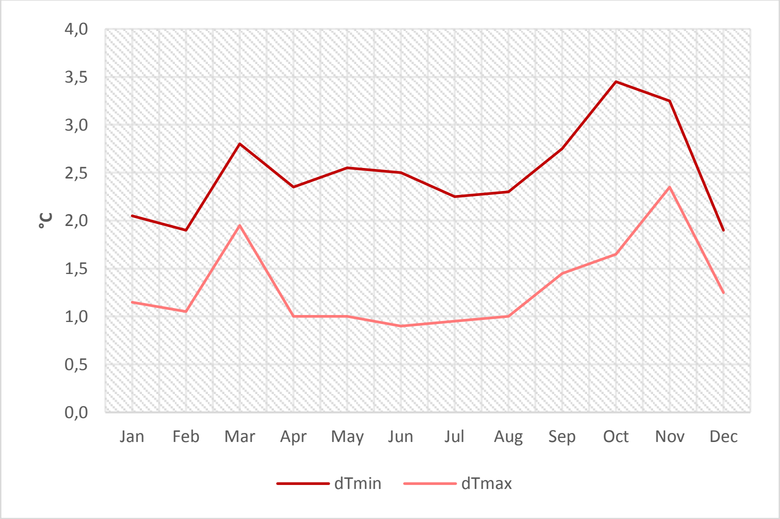


Figure 22. Projected average increase in minimum and maximum temperatures 2010 – 2050 in Bamrang Khola. °C.

The downscaled projections show the average change in maximum and minimum temperatures per month and the change in monthly precipitation from the reference period 1996 – 2005 to the periods 2030 – 2050 and 2050 – 2080. For the microeconomic model, we need to refer to changes between two years, and use the average over the same reference period to represent the climate in 2010, and the average of the period 2030 – 2080 to represent the climate in 2050. The period used to represent climate change is thereby somewhat longer than the period than the period over which we assess the socioeconomic impacts, which is 2010 – 2050. Figure 22 and Figure 23 show the projections for max and min temperature and for precipitation, respectively, in 2050.

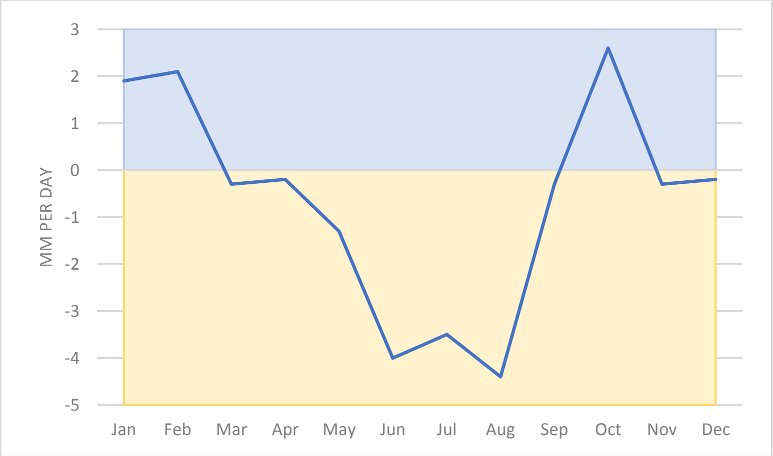


Figure 23. Projected average change in precipitation 2010 to 1050 in Bamrang Khola. mm per day.

Similar to the projections for Nepal, there is a significant increase in projected temperature in Bamrang Khola, and higher than for the average of Nepal. Minimum temperature increases by 2.5 °C per year and maximum temperature by 1.3 °C per year, but a little lower during the first eight months and higher after the monsoon from September until November. There is no significant change in precipitation, but the projections indicate lower precipitation during the monsoon.

The impacts on the productivity at the farms vary depending on crop. Figure 24 displays the growing seasons for the different crops during the year. The estimates of the impact on each crop are based on the monthly change in temperature and precipitation over the growing season. Here, the impact functions used previously are replaced with specific estimates for impacts on the growth of each crop. Assessments of impacts related to change in minimum temperature, maximum temperature and precipitation for the different crops were provided by Dhakal (2014), and used to estimate the annual impact on the average farm.

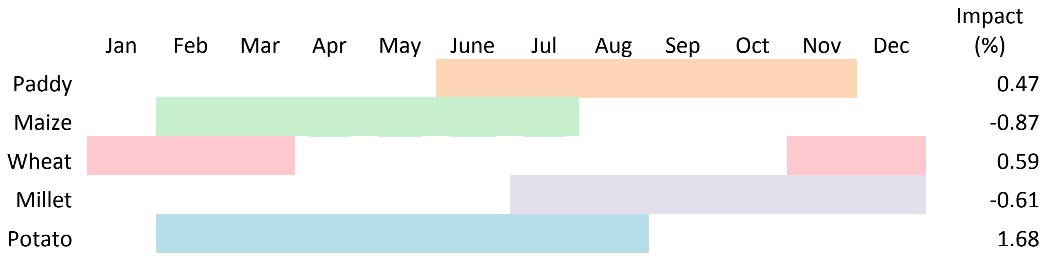


Table 24. Growing season and impact of climate change in 2050 by crop in mid-hills Khotang

As it appears, the impacts on the crops are very small, and with a positive effect on the yields of potato of less than 2 % as the largest impact. For livestock, we use a weighted average of the impacts on crops over the year, which gives an increase of 0.36 %. The aggregated output on farms thereby increases by 0.04 %. Practically speaking, then, there are no impacts of climate change on the productivity of land in Bamrang Khola, according to these projections, as opposed to the 2.7 percent reduction in the calculated productivity for the agricultural sector in Nepal. Note, however, that this is not to be interpreted as an argument for not being concerned about climate change in this area. First, the time perspective is relatively short. The climatic changes in the scenario considered here, RCP8.5, are moderate in 2050. Later in the century, the changes are larger and impacts become much stronger. Second, the estimates are based on monthly averages over a long period, meaning that possible changes in the frequency of extreme events may change. This is not considered in this study.

While the productivity of land is nearly unaffected by the projected climatic changes in Bamrang Khola, the health effects of the temperature increase are stronger in this area than in Nepal in general. There are no separate studies of the health effects on smallholders in this area. Therefore, we use the same impact function as for labour productivity in agriculture in Nepal in general, without distinguishing age groups or gender. We have no indications on what type of work is the main activity outside the farm, meaning that the impacts on work outside farm is assumed equal to the impacts on work on farm. As a result, reduction in the productivity of work, both on farm and outside farm, is estimated to 5.13 %.

The resulting impacts on output, consumption and work for the five groups defined in Section 6 are shown in Figure 25. They can be interpreted entirely as impacts of health effects. Lower productivity of work is negative for all groups, but there is a clear difference between the smaller farms, which are subject to the output constraint, and the larger farms. The relative reduction in income is stronger on the smallest farms, and enforces a stronger reduction in the consumption of market goods as well. Thus, while the consumption on smaller farms becomes more dependent on the output on own farm, the larger farms manage to balance the reduction in consumption. This applies, in particular, to unconstrained farms, where there is a room for more work on the farm to sell more goods to the market, and thereby limit the loss of income. As a result, the reduction in consumption of food from farm is higher than on the other farms, but the reduction in consumption of market goods is limited.

Figure 25. Impacts of local climate change on income, consumption and work by group. Percent.

Note that the main difference between the impacts on unconstrained farms and farms subject to the hiring constraint is the change in the work on farm. This is because the farmers on the largest farms spend all their time on the farm, but consume less food than produced. Therefore, they are able to balance their reduction in the consumption of consumer goods, and thereby avoid the unbalanced reduction in consumption that farmers subject to the output constraint are forced to do. Moreover, the relevance of a hiring constraint may differ considerably across farms. The model assumes that if there is a need to engage workers outside the farm, the farmer has to pay more than they earn by working outside the farm themselves. This may differ considerably from farm to farm.

The significant contributions from remittances in the survey shows that members of the household may earn far more by working outside the farm instead of working there. Hence, the focus on the agricultural activity in this report has to be emphasized. Another aspect, which is not addressed here, is the opportunities people in the communities have to exchange both labour and farm output instead of buying and selling to each other. The different seasons for different crops implies that farmers may help harvesting on other farms in one time of the year in exchange of getting help from others in the harvesting on their own farm. This helps cancelling out the difference between what they have to pay and what they earn, meaning that the impacts on farms subject to the hiring constraint become similar to those on unconstrained farms.

Another result of the lower productivity of labour is a shift in the distribution of farm groups. Lower productivity implies a potential increase in farms subject to the nutrition constraint, but the change is negligible in this case. The output constraints applies to fewer farms, as 8.6 percent of the farms shift from running under an output constraint to a conditional output constraint. 6.8 percent of the farms shift from conditional output constraint to unconstrained farms, while 2.3 percent of the unconstrained farms become subject to the hiring constraint. These shifts contribute to moderate the negative impacts on the farms in question, primarily for those shifting from conditionally constrained to unconstrained farms.

Finally, note that these runs are based on mere assumptions about the relationship between a maximum time for work and size of the farm. The assumption refers to the findings in the survey, which show a clear increase in the total time spent on work both inside and outside the farm with increasing farm size. However, the survey do not give sufficient information to quantify this relationship. A check of the sensitivity of this assumption shows that two main changes appears if the ability to work is even more sensitive to the farm size. First, the impacts of the health effect on farms subject to a conditional output constraint are much lower, primarily because many these farms become unconstrained farms, and second, a larger part of the farms falls below the nutrition constraint because of the health effects.

7 Conclusions

This report takes three research perspectives as its point of departure. The first is the climatic changes, which are based on global climate projections with derived downscaled projections for Hindu-Kush Himalaya. The second is the economic development in the region. We use macroeconomic projections for China, India, Pakistan, Nepal and Bangladesh under a global development that generates greenhouse gas emissions equal to those underlying the climate projections. These correspond to RCP8.5, and the model is run until 2050. The third perspective is that of smallholder farming in a community in Nepal, who are impacted by the climatic changes directly and via the resulting impacts on general economic development.

The climate projections provide information on changes in precipitation and temperature on a monthly basis, and with 12x12 km resolution. The socioeconomic projections refer, on the other hand, to national data on annual basis. The climate projections therefore had to be reinterpreted, and expressed by the annual mean changes at a country level. To capture variations over the year and across districts, one can use weighted averages from the climate projections. This study uses weights that reflect population densities in the different grid points. For the local study, the downscaled projections were used to estimate the impacts on smallholders in the community of Bamrang Khola in Khotang. In addition, the community is affected by the related consequences for economic development, which are reflected in the impacts on prices of goods and services, and on wages.

Combining the three perspectives implies that some aspects from each study get lost, in particular from the climate projections and from findings in the many studies of local communities. What is gained by considering the three perspectives in context is that it enables identification of impacts on social and economic factors that put leads on how climate change affects a community, but are determined by impacts and responses outside the community. This information is essential for development of adaptation strategies.

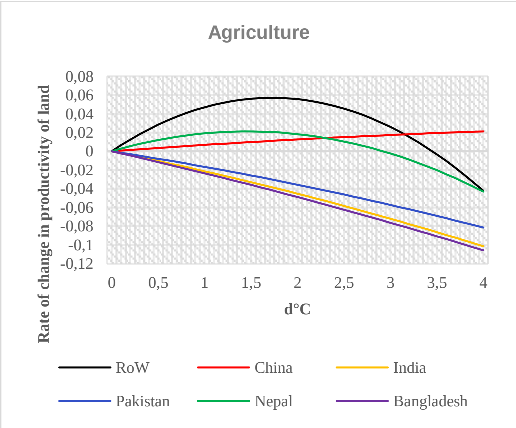
In the medium term considered here, the impacts of climate change in Hindi-Kush-Himalaya are moderate, according to this study, although varying across the five countries addressed. A look at the relative differences between impacts evaluated from different perspectives nevertheless provide important lessons. We mention firstly, that there is a notable difference between impacts to the economy in countries in the region and the impacts to people living there. Factors that help moderate the impacts to the economy of a country, such as price effects, may make things worse to most of the population. Secondly, smallholders are particularly vulnerable to climate change, but the vulnerabilities differ. The least affected are those who are able to take advantage of market effects, because this improves their adaptive capacity. Thirdly, while the intuitive focus in assessing impacts of climate change to smallholders is to consider the impacts on crop yields and livestock, other effects may be equally, if not more important. In this study, impacts on crop yields is negligible in one case, but health effects implies stronger negative impacts than if the impacts are divided equally between health effects and crop yields. One reason is the negative impacts on labour productivity and wage levels.

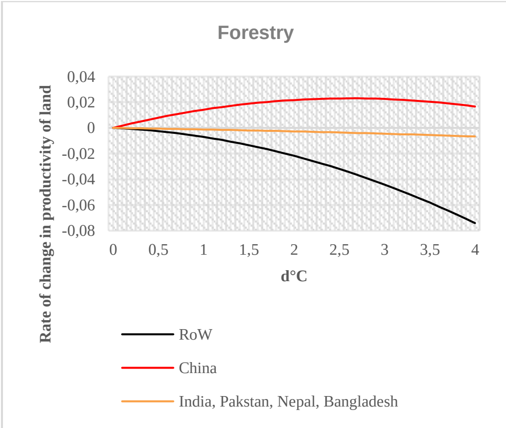
The large share of poor people in Hindu-Kush Himalaya highlights the importance of achieving economic development in the region. A straightforward reason is that it is better to be rich that being poor. From the perspective of adaptation to climate change, the main reason is that economic development enhances the adaptive capacity of smallholders, however. They do so because they get increasingly involved in market transactions, and thereby become more flexible regarding provision of goods and services they need in their daily life. The message is, therefore, that a national strategy for building resilience to climate change is to prepare the ground for a careful expansion of market opportunities for smallholders.

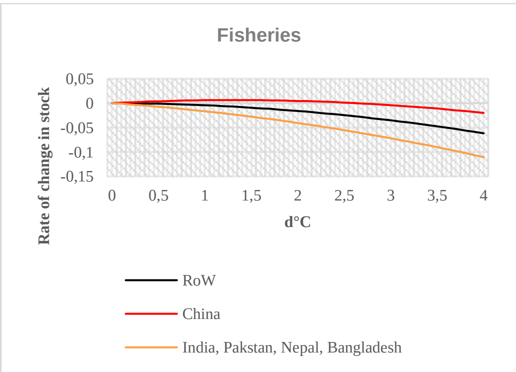
Economic growth by itself does not suffice unless it gains the whole population. If the growth is limited to a few areas or to a part of the population, this study indicates that the impacts of climate change for the remaining part of the population may become worse. The reason is that changing markets related to climate impacts affect everybody. It benefits only those farmers who produce for the market, who are able to take the full advantage of increasing food prices, while smallholders stand to lose because of the constraints they are living under.

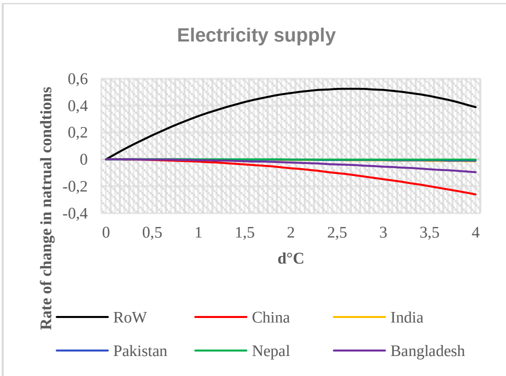
APPENDIX 1

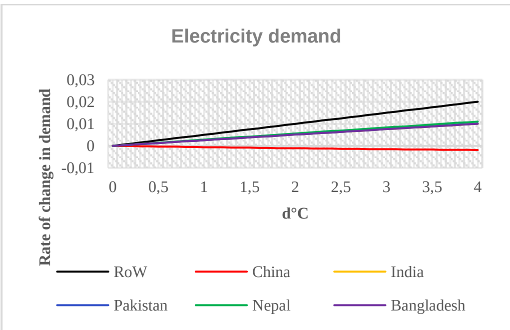
Rates of change in sector productivity, demand and input productivity at increasing temperature.

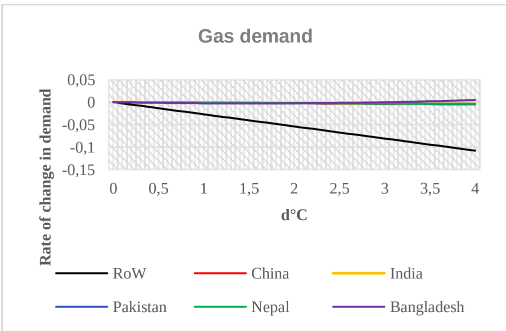


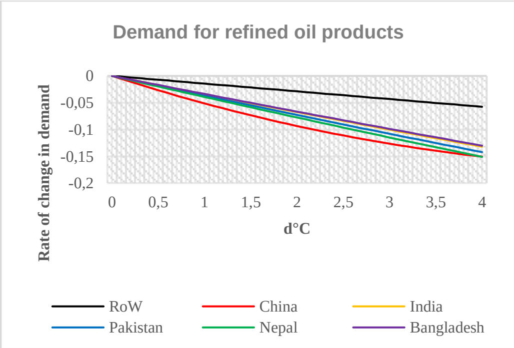


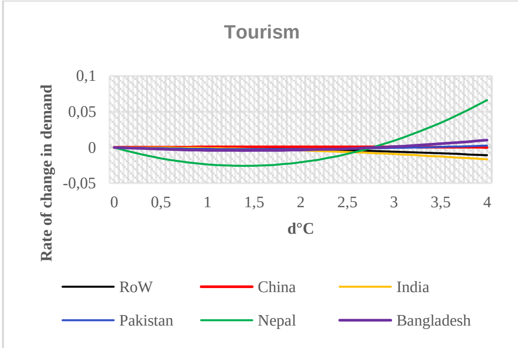


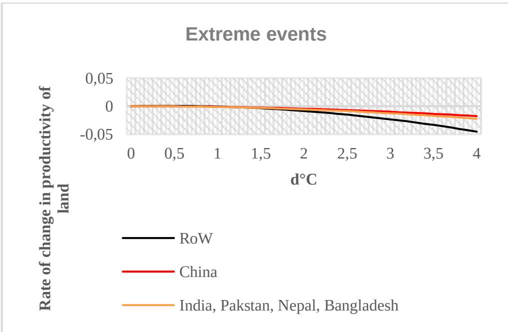


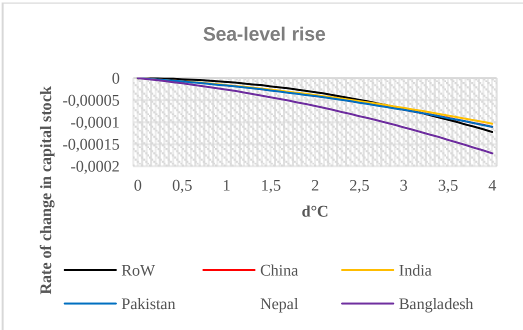




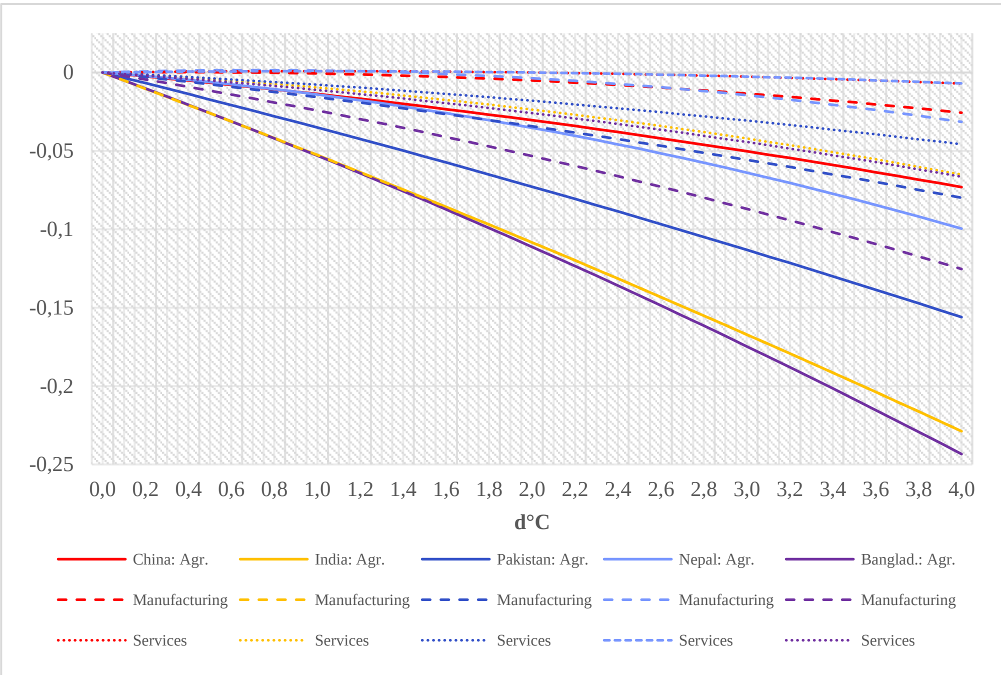








Rates of change in productivity of labour of health effects in agriculture, manufacturing and services.



APPENDIX 2

Model for smallholder farming

The model for smallholders relates the production on the farm to the availability, or ownership, of land of each household. The output on the farm can be consumed by the household, while monetary income can be generated both by selling products from the farm and by work outside the farm. We use an adapted version of the model in Aaheim et al. (2013) and Aaheim et al. (2016b), where the production on a farm is related how much time farmers spend on working on the farm, n_f^i, and the availability of land, r^i. The aggregated production from agriculture, X, is the sum of output from the total number of farms N:

$$X = \sum_{i=1}^{N} f({n_f}^i, r^i) \quad \text{(A.1)}$$

The production at each farm is divided into one part, x_f, which is consumed directly by the family on the farm, and one part, x_m, which sold in the market at a price p. If the customers come to the farm to buy food, the monetary income from farming is px_m. In most cases, however, there are costs related to selling the products, which we denote as a transaction cost t_x, meaning that the income from selling products from farm i is $(p – t_x)x_m^i$. The time farmers need to spend on working on the farm depends on the farm size. The total time available to work, $\bar{n}$, may also give room for work outside the farm at a wage w.

The income from selling products and from paid work is spent on buying a quantity of food in the market, x_m, and buying other goods, z_i, at a price q. Below, we focus on single farms only, and drop the scripts i. Then, the monetary budget constraint for each household is, then:

$$(p_x - t_x)\left[f\left(n_f, r_i\right) - x_f\right] + w\left(\bar{n} - n_f\right) = px_m + qz_i \quad \text{(A.2)}$$

Similar to the motivation behind the behaviour of farmers in the macroeconomic model, we assume that also the smallholders maximize their utility of consumption, $U(x_f, x_m, z_i)$. In addition to the budget constraint (A.2), farmers cannot consume more from their own farm than they produce, meaning that

$$f\left(n_f, r_i\right) \geq x_f \quad \text{(A.3)}$$

In addition we impose a minimum amount of food needed to survive, $\bar{x}$, which we call a nutrition constraint:

$$\bar{x} \leq x_f + x_m \quad \text{(A.4)}$$

Maximization of utility gives one set of first order conditions for the consumption of the goods x_i^f, x_i^m, z_i

$$\frac{U'_{x^f} - \mu - \sigma}{p_x - t_x} = \frac{U'_{x^m} - \sigma}{p_x} = \frac{U'_z}{q} \quad \text{(A.5)}$$

and one condition for the spending of time

$$(\lambda(p - t_x) - \mu)f'_n = w \quad \text{(A.6)}$$

λ, μ, and σ in (A.5) and (A.6) are the shadow prices related to the budget constraint (A.2), the output constraint (A.3) and the nutrition constraint (A.4), respectively. Usually, all goods and services are measured in prices in economic models. Then, the shadow price of the budget constraint can be interpreted as the marginal value of money, which is set equal to the price of a numeraire. The model thereby solves prices of other goods and services relative to the price of the numeraire. To keep this assumption valid in our case, where food from the farm is not subject to the monetary budget constraint, we consider a separable welfare function, which is optimized in two steps. First, x_f and x_m is determined by minimizing the cost of consuming a given, total amount of food $x = x_f + x_m$. In the second step, market consumption is optimized given the monetary budget constraint. This means that the welfare function used in this study can be written as

$$U(x_f, x_m, z_i) = u(x_f | x_m) + v(x_m, z) \qquad \text{(A.7)}$$

Whether the constraints on food consumption (A.3) and (A.4) are binding or not depends on the farm size. If both constraints are binding, the consumption of food is, in principle, fixed by these constraints. Then, farmers have to consume as much food from the farm as they can produce, meaning that they spend the time to work on the farm necessary to do so. The rest of the time, they can work off the farm, and buy the food necessary to meet the nutrition constraint. Since this constraint is binding, they buy more food than they would have done without this constraint, meaning that if there is money left, they will buy other goods. The allocation of both working time and consumption is thereby fixed. This means that there is no use in running the model in these cases, but it is important to identify the farm size below which the nutrition constraint is binding.

For the quantification of the model, we assume constant elasticity of substitution both in describing the production on farms and the utility of consumption. Under the optimizing behaviour in the model, this implies that the use of two goods changes proportionally with changes in relative prices, regardless of the composite of the two goods. In this study, the degree of proportionality, or elasticities of substitution, are imposed by assumption. Then, the production function can be written as

$$f(n_f, r) = B\left(\beta n_f^{\gamma} + (1-\beta) r^{\gamma}\right)^{\frac{1}{\gamma}} \qquad \text{(A.8)}$$

A and α are parameters calibrated from the survey, and $1/(1-\gamma)$ is the assumed constant elasticity of substitution. Similarly, we have two utility functions, according to (A.7), one for consumption of food:

$$u(x_f, x_m) = \left(\alpha_x x_f^{\rho_x} + (1-\alpha_x) x_m{}^{\rho_x}\right)^{\frac{1}{\rho_x}} \qquad \text{(A.9)}$$

And one for consumption of market goods

$$v(x_m, z) = \left(\alpha_m x_m^{\rho_m} + (1-\alpha_m) z^{\rho_m}\right)^{\frac{1}{\rho_m}} \qquad \text{(A.10)}$$

The parameters α_x are α_m are calibrated from the survey, while $1/(1-\rho_x)$ and $1/(1-\rho_m)$ are the respective assumed elasticities of substitution in consumption. From the income constraint in (A.2), we can derive the demand for market goods by use of (A.10), which gives the demand functions

$$x_m = i\left(\left(\frac{p^{\rho m}}{\alpha_m}\right)^{\frac{1}{1-\rho m}} + \left(\frac{q^{\rho m}}{1-\alpha_m}\right)^{\frac{1}{1-\rho m}}\right)^{-1} \left(\frac{p}{\alpha_m}\right)^{\frac{1}{\rho m-1}} \qquad \text{(A11)}$$

$$z = i\left(\left(\frac{p^{\rho m}}{\alpha_m}\right)^{\frac{1}{1-\rho m}} + \left(\frac{q^{\rho m}}{1-\alpha_m}\right)^{\frac{1}{1-\rho m}}\right)^{-1} \left(\frac{q}{1-\alpha_m}\right)^{\frac{1}{\rho m-1}} \qquad \text{(A12)}$$

The income, i, is defined by the left hand side of (A.2). When the consumption of market-based food consumption is given, the consumption of food from own farm, x_f, can be expressed as the ratio of x_m in case all the consumption of the family were paid by monetary income. This ratio can be found by "shadow demand functions" corresponding to (A11) and (A12), but derived from (A.9). Then,

$$x_f = \left(\frac{(1-\alpha_x)(p-t_x-\mu)}{\alpha_x p}\right)^{\frac{1}{\rho_x - 1}} x_m \quad \text{(A.13)}$$

Equations (A.11) – (A.13) are specifications of the general optimization conditions in (A.4), where the shadow price of the nutrition constraint, $\sigma = 0$, as the composite of consumption and the division of work is given by the size of the farm in case $\sigma > 0$. As all the quantities refer to a monetary numeraire, the budget constraint, $\lambda = 1$, meaning that the condition for spending of time (A.6) is

$$w = (p - t_x - \mu)\alpha A n^{\gamma-1}\left(\alpha n_f^{\gamma} + (1-\alpha) r^{\gamma}\right)^{\frac{1}{\gamma}-1} \quad \text{(A.14)}$$

Now, the left hand side of (A.2), which defines the monetary income, i, the output constraint (A.3), and the five equations (A.8), (A.11), (A12), (A.13) solve the seven unknowns, i, μ, y (= $f(n_f, r)$), x_m, z, x_f, and n_f.

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