Climate change adaptation, agriculture and poverty: A general equilibrium analysis for Nepal

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Abstract

This paper presents a model of climate change adaptation in the Nepalese economy and uses it to simulate long-run impacts of climate change and cropland re-allocation on household poverty. We develop a computable general equilibrium (CGE) model for Nepal, with a nested set of constant elasticity of transformation (CET) functional forms to model the allocation of land within different agricultural sectors. Supply of land depends on the magnitude of effects of climate change on different crops. Land transformation elasticities in the CET functions reflect the ease of switching from one crop to another based on their agronomic characteristics and degree of impacts of climate change. The distinguishing feature of the model is flexibility of CET values. Use of a set of CET values at the sectoral level thus captures the transformation effects of agronomic feasibility and profitability of crops while, at the same time, retaining the role of price relativity in the demand side of land along with other factors of production. The results suggest that, in the long run, farmers tend to allocate land to crops that are comparatively less impacted by climate change, such as paddy. Furthermore, the results reveal that land re-allocation tends to reduce income disparity among household groups and poverty by significantly moderating the income losses of marginal farmers.

JEL Classification: Q54, Q15, I32, C68

Keywords: Climate change adaptation; poverty; general equilibrium model; land re-allocation; Nepalese agriculture; South Asia

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1. Introduction

A significantly growing body of literature shows that climate change threatens the objective of sustainable development eliminating poverty. This situation is alarmingly enhancing the vulnerable people and developing countries to enter into a vicious poverty cycle. Given the importance of agriculture to people's livelihoods in these countries such as Nepal, climate change induced loss of agricultural productivity is one of the main reasons behind such a continuous poverty cycle. Other agriculture-related reasons for the escalating poverty in these developing countries are: floods, or droughts; crop failure from reduced rainfall; and spikes in food prices that follow extreme weather events (Chalise, Naranpanawa, Bandara, & Sarker, 2017). In this situation, even optimal success in global action towards mitigating climate change will be insufficient to build resilience and compensate for the damage cost (IPCC, 2013; Nelson & Shively, 2014). An effective framework of potential adaptations is essential to eradicate the escalating poverty in developing countries (Arndt, Robinson, & Willenbockel, 2011; UNFCCC, 2015). In the absence of such a consolidated framework of adaptation options, ending poverty will not be possible if climate change and its effects on poor people are not accounted for and managed in development and poverty-reduction policies.

Moreover, it is important to implement locally led adaptations to climate change in agriculture, particularly, when smallholders have inadequate access to official strategies. In this sense, farmers' practices, which are based on their ad-hoc experiences, such as changing crop patterns, improving grazing patterns, cultivating heat-resistant crops, using better fertilizers, and using rain-water harvesting for irrigation, can help to reduce the impacts of climate change. However, it is unknown what the maximum benefit smallholders in developing countries can enjoy from such adaptations (Chalise & Naranpanawa, 2016).

Gradually re-allocating land from high-impact crops to low-impact ones is one of the best adaptation options that farmers have been experimenting with to minimise the impacts of climate change. As climate-induced impacts are highly variable among crops and croplands due to different agronomic conditions, farmers tend to supply more land to less-impacted crops in order to maximise their yields. Re-allocating land for climate-smart crops is crucial not only for food security and the overall economic growth of the agricultural sector but also for helping the poorest people in developing countries to escape the cycle of poverty. However, farmers in developing countries are facing significant challenges in understanding the actual agronomic feasibility of switching crops and viability of land-use change practices that maximise farm revenue as well as overall economic wellbeing (Chalise & Naranpanawa, 2016). In this sense, a study on assessing the impacts of climate change and the benefits of the land re-allocation as an adaptation practice to reduce poverty will attempt to fill the gap in available literature.

Although there is clear evidence that agricultural systems in developing countries are highly vulnerable to climate change, there have been relatively few detailed studies carried out to examine the potential of climate-change adaptations on agriculture. Some partial equilibrium studies (e.g., Kumar, 2011; Mendelsohn, 2007; Saito, 2012; Seo, Mendelsohn, Dinar, Hassan, & Kurukulasuriya, 2009) have attempted to assess the impacts of climate change and possible climate-change adaptations on agriculture at national and global levels. However, these studies have three major limitations. First, their results are skewed towards individual perceptions and practices, and the uncertainty and long timeframes allied with climate change limit the findings. Second, most of these studies emphasise crop production as one of the major characteristics of partial equilibrium analysis (as mentioned in Elbehri & Burfisher, 2015), and disregard direct and indirect linkages with the overall economy. Third, none of these studies has investigated climate-change adaptations in relation to differences between households and their level of poverty.

A few studies consider the economy-wide impacts of climate change on agriculture. In an economy-wide approach, top-down computable general equilibrium (CGE) modelling is generally used (e.g., Bandara & Cai, 2014; Bezabih, Chambwera, & Stage, 2011; Chalise & Naranpanawa, 2016; Chalise et al., 2017; Eboli, Parrado, & Roson, 2010; Robinson et al., 2014) for assessing the economic effects of climate change and evaluating the efficacy of climate policies. These studies have found that unfavourable climate change in several developing countries is not only likely to induce discrepancies in income and consumption but also bring about a huge decline in their overall economic performance.

Table 1 summarises a comprehensive survey on climate-change impacts on Nepalese agriculture. According to Joshi, Maharjan, and Piya (2011), a time series regression analysis of 1977—2008 shows a positive impact of climate variability, with increases in rice, wheat and maize of 1.7%, 2.32% and 1.49% respectively. However, a future projection on the basis of these results is not meaningful as climate change has non-linear impacts on crops, and technological advancement which is not included in the model, could have sole impacts in this case. Cline (2007) has reviewed the different approaches of various assessments, and estimated the impacts of climate change on agricultural products globally by 2080; overall agricultural productivity in Nepal is estimated to decline by 17.3% if no adaptation or carbon fertilisation strategies are implemented and the rate of current technological growth continues.

[Table 1 here]

Similarly, Knox, Hess, Daccache, and Perez Ortola (2011), on the basis of their literature survey, have projected an average change in agricultural productivity in Africa and Asia, which is almost consistent with Hertel, Burke, and Lobell (2010) and Bandara and Cai (2014). Hertel et al. (2010) have provided a range of productivity change for all the countries in the world. Some India-based studies[2] (e.g., Auffhammer, Ramanathan, & Vincent, 2012; Byjesh, Kumar, & Aggarwal, 2010; Kumar, 2011; Kumar & Parikh, 2001) have predicted a range of significant productivity loss in Indian agriculture. Overall, some literature expects notably positive impacts

[2] A few studies on Indian agriculture are reviewed in this paper, as they have revealed that Indian agriculture is similar to Nepalese farming in many respects (e.g., rain-fed agricultural system, level of technological advancement, and cropping-weather pattern).

of climate change in certain crops. For example, rice yields are expected to increase till 2030, and some assessments (e.g., Iglesias & Rosensweig, 2010; Thapa & Joshi, 2011) have projected a positive impact of climate change on rice and wheat until 2080. Despite the variations in estimates of productivity losses due to climate change in Nepalese agriculture, a range of these estimations can be used as inputs for our simulation experiment.

In contrast to the existing comparative-static CGE assessments of climate-change impacts on agriculture production (e.g., Arndt, Strzepeck, et al., 2011; Bosello & Zhang, 2005; Hertel, Rose, Tol, Taylor, & Francis, 2009), the approach presented here is able to capture the possible land re-allocation for several crops.

Although recent studies (e.g., Fujimori, Hasegawa, Masui, & Takahashi, 2014; Hertel et al., 2010; Li, Taheripour, Preckel, & Tyner, 2012; Palatnik et al., 2011) have used CET in land substitution systems, the results have some serious limitations. First, the results are limited to a few agricultural sectors where, we argue, there is an extreme chance of an individual sector controlling the overall model results. Second, these studies have not tested the possibility of crop switching with a range of CET values. As CET parameters are not econometrically estimated a sensitivity analysis of CET parameter values would give more robust results. These limitations have created a serious gap in the evidence based policy recommendations, in which the implication of such beneficial land re-allocation to local farmers is missing.

In this study we develop a multi-houshold CGE model for Nepal to analyse the impact of climate change on the agriculture sector and also to examine the economic impact of land re-allocation as an adaptation straergy to minimise the cost of climate change, and to reduce poverty. A recent study on climate change adaptation (Chalise & Naranpanawa, 2016) has used a framework of land-use change to see the benefits in Nepalese agricultural system, however, the study has not analysed the changes in poverty level due to climate change impacts and adpatation. To the best of our knowledge this is the first attempt in Nepal to analyse the relationship of climate change impacts as well as an adaptation startegy with poverty, using the general equilibrium framework. In this model we attempt to model the land supply using a nested Constant Elasticity of Transformation (CET) functional form.

Therefore, the main objective of this paper is to modify the widely used assumption of "fixed land supply for a given industry" in CGE models, by allowing farmers to supply land to crops that are less affected by climate change, subject to any agronomic constraints; and to examine the economy-wide impacts, industry impacts and household level impacts including household poverty of climate change-induced agricultural loss both "with" and "without" land re-allocation in Nepal.

The rest of the paper is organised as follows: next section illustrates the model, including the modifications to land re-allocation function. Section 3 depicts the simulation results; and Section 4 presents some conclusions.

2. The Model

When quantifying climate-change impacts and possible adaptation strategies in agriculture, it is difficult to assess the effects of all the factors that are being driven by climate change. The CGE models have frequently been used to model the economy-wide impacts of different shocks acting individually or collectively on a single country or multiple countries. Hence, a CGE model makes an ideal analytical framework to model the climate change impacts and adaptation strategies simultaneously on a single country. However, the recent studies which used global CGE models (e.g., Hertel et al., 2010; Müller & Robertson, 2014; Nelson & Shively, 2014) and South Asian CGE models (e.g., Ahmed & Suphachalasai, 2014; Bandara & Cai, 2014) to evaluate climate-change impacts on agriculture have created a substantial research gap by ignoring the potential impact of climate change adaptations by farmers. Thus, a single-country, multi-household CGE model with the appropriate inclusion of potential adaptations in agriculture can capture the discrepancies in income and consumption as well as changes in household-level poverty due to climate-change-induced impacts in agriculture.

This paper uses a comparative-static CGE model, based on the ORANI-G model, following the tradition of the applied general equilibrium approach pioneered by Dixon, Parmenter, Sutton, and Vincent (1982). This Nepal CGE model (hereafter GEMNEP) modifies the South African CGE model developed by Horridge et al. (1995), and closely follows the Nepalese CGE model developed by Chalise and Naranpanawa (2016). As in any generic CGE model, producers are assumed to maximise profits subject to resource constraints and consumers are assumed to maximise utility subject to budget constraints. Moreover, this model also follows other assumptions: export demand is negatively related to export prices; government expenditure is exogenously determined; consumers, producers and other agents are assumed to be price takers, not price makers; and the entire product and factor markets follow the market-clearing assumption of demand equals supply.

This model consists of 57 industries, 57 commodities, 3 factors, 7 household groups and 10 skill/occupation types (see Appendix C and D). Household incomes are determined by their possession of 3 production factors (land, labour and capital) and the market returns to these factors. The model comprises a set of nested Constant Elasticity of Substitution (CES) functions for specifying production technologies and consumer demands for final goods and services. Households, government and the rest of the world are the major agents that demand the final goods for their consumption. In the same way, we specify a CES function for an intermediate mix. Production of final goods and services is the combination of intermediate inputs and primary factors. The primary factors (land, labour and capital) are aggregated through a CES function with a sub-set of CES functions for different types of occupations and a CET function for land supply (see the CET specification in the next part of this section).

In order to incorporate the key characteristics of household types, occupational skills and their linkages to the rest of the economy, we extend the basic CGE model in two dimensions. First, given that a comparative analysis of climate-change impacts is important for identifying winners and losers, we follow Horridge et al. (1995) and Chalise and Naranpanawa (2016) and introduce seven types of households on the basis of their characteristics, such as hectares of agricultural land that they hold and household head's level of education (see Appendix C). The purpose of defining household groups in this way is to introduce heterogeneity with respect to urban/rural livelihood, mountain/hill/lowland topography, and high/low education. In doing so, we use the Nepalese National Living Standard Survey database (CBS, 2011b) to disaggregate households' final consumption and returns from primary factors. Second, to allow for differential effects in the employment of skill categories, we introduce 10 occupation types and explicitly model the heterogeneity of levels of income.

[Diagram 1 here]

In this model, "Rest of the world" is an agent that links the exports and imports of goods and services with the national economy. In this case, a CES function is also specified to represent consumers' choices/decisions between domestic and imported goods, aggregating the final demand composite. The relative prices of goods and services are determined on the basis of real exchange rate as a numeraire such that income in household level is influenced by relative prices rather than absolute ones. To represent that saving equal investment, savings-driven income flow is assumed analogous to investments that are used only for final commodities. Capital and labour are perfectly mobile within the industry sectors. As there is a scientific consensus that the impacts of climate change can be realised distinctly within a 30—40 year period, a long-run closure (see Diagram 1) is set for our model simulation to avoid the uncertainty of transitional projection. At the macro-level, GDP, household consumption, investment, public spending, real wages and capital stock are treated as endogenous. Total employment, technical changes, capital rate of return and terms of trade are treated as exogenous.

CET function of land re-allocation

The proposed model adds an important land supply equation to the original ORANI-G model, including linearisation of profit maximisation subject to the cost of inputs. As land rentals across different land usage suggest that land does not move freely between alternatives, the only way to model land supply is to use a CET function. In doing so, we assume that producers seek to maximise returns from land producing given levels of output by supplying extra land to industries that experience significantly fewer impacts of climate change. Thus, the maximisation of return can be presented as a constrained optimisation problem, where producers choose land, X_i *(i = 1… k……..n)*, to maximise the total returns from the inputs of producing a given output, Y, subject to the CET production function:

$$Y = \alpha\left[\sum_{i=1}^{n} \delta_i X_i^{\rho}\right]^{1/\rho} \quad (1)$$

and objective function: $Max\ TR = \sum_{i=1}^{n} P_i X_i$

Where, δ is share of land, and δ>0. α and ρ are parameters, and ρ >1. X_i is a plot of land allocated, for *i* is equal to *1* to '*n*' crops. P_i is profit of an effective land unit. δ_i and ρ are behavioural parameters and *TR* is the total revenue generated from the land. To solve the model in the level forms, the values of δ_i are normally determined in a base-year calibration procedure. The land area balance is therefore maintained in the base year. However, area balance is not guaranteed if either the relationship among the nested land shares or the relative prices are changed from the values used in the calibration. To fix the X_i, it is natural to allocate arbitrary values to P_k, say 1. This simply sets appropriate units for the X_i (in base-period-dollars).

The Lagrangian equation for the above problem can be written as follows:

$$L = \sum_{i=1}^{n} P_i X_i + \Lambda\left[Y - \left(\sum_{i=1}^{n} \delta_i X_i^{\rho}\right)^{\frac{1}{\rho}}\right] \quad (2)$$

From which (see Equation *E3* to Equation *E13* in Appendix D for the complete derivation), we have, for a particular industry, *k*:

$$X_k = Y \left\{ \sum_{i=1}^{n} \delta_i \left(\frac{P_i \delta_k}{P_k \delta_i} \right)^{\frac{\rho}{(\rho-1)}} \right\}^{-\frac{1}{\rho}} \tag{3}$$

Equation (4) can be transformed into a linear percentage form as follows:

$$x_k = z - \sigma(p_{ave} - p_k) \tag{4}$$

Where, z is the total agricultural land, x_k is the land allocated for a particular industry, k, and maximising the return from a unit plot of land is the principal objective of the producers. This is determined by farmers' decisions with respect to the degree of impact of climate change to that particular crop. σ is the CET parameter that is externally supplied in the model on the basis of agronomic feasibility. Mathematically, $\sigma = {}^{1}/_{(\rho - 1)}$. Similarly, p_k is the profitability per unit of effective land and p_{ave} is the average profitability per unit of effective land. Mathematically, $p_{ave} = \sum_i S_i p_i$, where, S_i is the share of industry, i, in total land profitability.

In the linear form (Equation 4), σ has the most important and debatable role in determining how each plot of land is allocated to particular crop. This is highly important because a small change in σ significantly changes the amount of land allocated. It is debatable because its value is supplied from outside. Unlike the CES function, the higher the value of σ, the greater the chance of allocating land to that particular crop. However, another factor determining the land allocation to a particular crop is profitability (p_k). Suppose that there is a hypothetical land plot and its use is to be decided according to the profitability from the crop planted. In this case, a detailed study on the agronomic feasibility of crop switching is required. It is irrelevant to use historical crop yielding to determine the land's profitability, as future impacts of climate change can substantially change its status. Therefore, this paper has linked climate change—induced productivity change with the profitability of crops in Nepal.

A problem with the CET function is that it implies that the elasticity of transformation is identical for all pairs of crops (Powell & Gruen, 1968). It is almost impossible to use Equation 4 to address the heterogeneity of several agricultural sectors. The only way to deal with this problem is by arranging the CET function in a nest. In doing so, the arguments of the function are split into pairs. Again, a major problem in nested CET functions is how to choose the pairs in a nest: this depends on agronomic characteristics and constraints. Because of these constraints, a set of pairs may include different crops in different agro-ecological zones. To address this issue, our model has used a set of CET parameters to test a range of climate change impacts on the overall economy.

As the main objective of this paper is to develop and test a general framework of land re-allocation, we develop a simple nest of CET functions with two levels. Out of 14 agricultural sectors, a nest of the paddy sector and other agricultural sectors is developed. A set of CET values is used to model the transferring the paddy land into the other 13 agricultural lands and vice versa. Similarly, a set of CET values is used to model transferring land between other pairs of crops within the 13 agricultural sectors. Although previous studies (e.g., Keeney & Hertel, 2009; Palatnik et al., 2011) have attempted to develop a nested set of agricultural sectors, their results are seriously limited by not testing a range of CET values for a single pair. It is difficult to recommend a land re-allocation framework without testing a set of feasibility parameters. Therefore, we develop a wide range of CET values, from highly inelastic to elastic to highly elastic, to test their feasibility and to recommend a framework to the local farmers of Nepal.

[Diagram 2 here]

In order to address the link between climate change—induced impacts in agricultural productivity and other parameters in the overall economy, we focus on the 14 agricultural industries[3] (out of the 57 sectors in the GTAP database— see Appendix D) in Nepal. From the impact assessment—related literature, a range of productivity shocks of rice, wheat, maize and other agricultural products are employed in the CGE model developed for this study (see Table

[3] Rice, wheat, cereal grains, vegetables fruits and nuts, oil seeds, sugar cane sugar beet, plant based fibers, other crops, bovine cattle sheep goats horses, animal products, raw milk, wool silk worms, forestry and fishing

2). The reasons for taking a range of impacts are, firstly, to address the irregular trend of assessment developed in previous literature. Secondly, the previous assessments have a different time frame of impact assessment, with the risk of extremely low or high estimations. Three scenarios (highest, medium and lowest) are developed for the simulations in this paper. Each scenario comprises three simulations. Diagram 2 presents the conceptual framework. Simulations H1, M1 and L1 assume that normal land allocation prevails and there is no change in land supply with respect to impacts of climate change. Each scenario has two other simulations, assuming that the land is mobile among industries. The first simulations (H2, M2 and L2) assume that the CET of paddy (CET1) is less than the CET of other agricultural sectors (CET2); and the second that CET1 is greater than CET2. The results are compared and analysed on the basis of changes in key macro-variables such as real GDP, real wages, household consumption and industry output.

[Table 2 here]

To analyse the discrepancies in household poverty level, this study attempts to measure income poverty within the seven household groups, namely, rural land-less households, rural land-small households, rural land-medium households, rural land-large households, urban low-education households, urban medium-education households and urban high-education households. A reason of classifying the household groups in this way is that income in rural areas of Nepal primarily depends on agricultural land owned by the households whereas urban household-incomes depend on level of education hold by household head (see detail household categories in Appendix C). In order to compare the pre- and post-simulation absolute poverty, the most popular money metric poverty indices of Foster, Greer and Thorbecke (FGT) (Foster, Greer, & Thorbecke, 1984) is considered. Changes in income due to climate-change impacts and land re-allocation in different seven household groups are adjusted to compare the poverty level. Poverty line also changes with changes in price level (Naranpanawa, Bandara, & Selvanathan, 2011). To address this issue of price change, changes in consumer price index (CPI) are used to determine the poverty line for each household in each simulation.

The overall base year poverty line is obtained by aggregating the food and the non-food poverty lines. The poverty line for Nepal, in average 2010–11 prices, has been estimated at Rs. 19,261; the food poverty line is Rs. 11,929 and the non-food poverty line is Rs. 7,332. The aggregated poverty line is used for this study. However, a set of poverty lines is used for seven different household groups for this study (see Table 3).

[Table 3 here]

3. Simulation Results

The results obtained from the simulations of the impacts of climate change and land re-allocation on Nepalese agriculture are analysed in three different stages: (1) changes in the overall macro-variables; (2) impacts at the industry level; and (3) impacts at the household level. As mentioned in the model section, every result is compared to the baseline status and reported as a percentage change. Deviation of the variables from the base year (a year without climate change and land re-allocation; our model uses 2011 as the base year) to a future year (which is determined with distinct climate-change impacts and land re-allocation; our model uses 2080) is evaluated. As demonstrated in Diagram 2, three distinct climate change scenarios (highest, medium and lowest) are simulated. In each climate change scenario, there are three simulations. In simulation 1 of each climate change impact scenario, the effects of climate change on poverty are analysed assuming that normal land allocation prevails and that the effects of land re-allocation among agricultural sectors can be ignored. In simulation 2 and 3 of respective climate change impact scenarios, crop switching by farmers to increase the availability of land to crops less impacted by climate change is represented by changes in the amount of farmland under less-impacted crops. As discussed in the previous section, simulation 2 and 3 are analysed with two different experiments on the basis of CET ratio: simulation 2 has CET1 < CET2 and simulation 3 has CET1 > CET2 (CET values range from 0.05 to 20).

Impacts in macro-variables

The percentage change results of important macro-economic variables over the base year values for above simulation experiments are summarised in Table 4.

[Table 4 here]

Real GDP is an important tool for evaluating a change in the overall economy due to the impacts of climate change and land re-allocation on agriculture. Moreover, the use of real GDP in terms of estimating changes in the Nepalese economy is important, as agriculture represents around 36% of the national GDP. Table 4 shows that, without land re-allocation, the projected impact of climate change on agricultural productivity affects real GDP negatively. In simulation 1, the real GDP is expected to decrease by 10.92% by 2080 in the highest impact scenario if smallholders do not adopt the land re-allocation strategy. Similarly, land transformation from paddy to other agricultural sectors may lead to a decrease in real GDP by 11.76%, which is again a worse situation than before. However, a correct way of land transformation (for example, simulations H3, M3 and L3) can lead to a better real GDP, such as a loss of only 9.66% in H3 simulation. In between simulation H2 and H3, the change in real GDP depends on the CET ratio. The higher the CET ratio, the less are the impacts of climate change on real GDP. A higher CET ratio means farmers are expected to re-allocate more land to less climate change impacted crops, such as paddy, from high climate change impacted crops such as maize. A similar trend of change in real GDP can be expected in the other two (medium and lowest) scenarios (see Table 4). A major factor of such a significant fall in GDP is the substantial fall in output of many agricultural products and other industrial outputs related to agriculture.

Regarding simulations 2 and 3, the change in real GDP depends on the CET ratio. The higher the CET ratio, the less the impacts of climate change on real GDP.

In the long-run simulations, it is assumed that the aggregate employment is fixed and thus the economy is in full employment. However, labour is allowed to be mobile between industries as well as between different labour categories. Implications of the above simulations on these labour movements are presented in terms of real wage (see Table 4). In the long-run closure, it is assumed that real wages are determined endogenously. Table 4 demonstrates the improvement in the real wages after simulation with land re-allocation strategy. The increase in real wages is due to the increase in the derived demand for labour, as a result of considerable expansion in activities of agricultural industries. Real GDP from the supply side is mainly determined by real wages.

Land re-allocation as climate-change adaptation in the long run improves real GDP. To understand the factors contributing to this change, the changes in each aggregate making up GDP from expenditure side should be decomposed. On the expenditure side, growth is mainly due to contributions from real household consumption (from -9.88% to -10.11% to -8.44% in the highest impact scenario, from -7.61% to -8.27% to -6.98% in the medium impact scenario, and from -2.36% to -3.18 to -1.97% in the lowest impact scenario). Consumer price index is also improved while comparing without and with land re-allocation as climate change adaptation strategy.

Impacts at industry level

Overall sectoral outputs are likely to be affected according to climate change—induced productivity loss in Nepalese agriculture. Table 5 shows the decrease in sectoral output and the improvement that can be achieved with land re-allocation. The climate-change impacts without any adaptation strategy lead to an increase in the cost of production as domestic and imported inputs become expensive. The implementation of land re-allocation as an adaptation strategy against climate change reduces the cost of production, as inputs become less expensive than without any sort of adaptation. As the consumer price index (CPI) goes high in the climate change scenarios without land re-allocation, the nominal wage rate goes high. However, land re-allocation helps to reduce CPI, resulting in a reduction in the nominal wage rate.

[Table 5 here]

As noted in Table 5, the manufacturing industries, along with the expansion of the agricultural industries, are also expected to expand significantly when farmers allocate more land to crops less impacted by climate change. In particular, industries such as dairy products, food products and processed rice have shown a marked increase in output while increasing the CET ratio, reflecting more land transformation possibilities. For example, the food production industry has shown a significant increase in output, from -14.79% to -6.32% in the highest impact scenario; from -11.47% to around -3% in the medium impact scenario; and from -2.42% to 5.41% in the lowest impact scenario. These improvements are responsible for the overall improvement in the manufacturing sector. Similarly, other industries such as dairy products and vegetable oils and fats have made a slight improvement in the output while increasing the CET ratio.

Impacts at household level

A substantial decrease in sectoral outputs, primarily in agricultural products, influences household income and consumption. To understand the considerable loss in GDP requires an estimation of the change in the individual parameters that determine the real GDP from the income side: land rents, labour wages, capital interests, profits and taxes. The major components of household income are rental income, wages and interest. We have to investigate the income of rural and urban households separately. As total employment is constant in the long run closure of the model, labour from other sectors moves to agriculture-based industries. As the cost of living goes up due to extreme inflationary prices, overall real wages decrease significantly. However, land re-allocation to climate-smart crops such as paddy can improve the loss in sectoral outputs and recover some of the household income and expenditure (see Table 6 and 7).

[Table 6 here]

As real GDP (from the expenditure side—see the last row of Diagram 1) is determined by the sum of household consumption, investment, government expenditure and net exports, the significant decrease in household consumption results in a huge decline in real GDP. Overall household consumption, which is shown in Table 4, clearly illustrates the important role of household expenditure in maintaining a progressive GDP. To understand the full effects of climate change—induced productivity loss, it is important to see the differences in impacts between various households. Table 7 shows the changes in consumption for different household groups. The table clearly differentiates the spread of impacts, as urban households are expected to experience a significantly greater decrease in consumption than rural ones. This is because urban households do not produce agricultural commodities and depend on highly priced products from the producers, who primarily belong to rural households. However, the patterns of consumptions are projected to improve if farmers allocate land to paddy as expected.

[Table 7 here]

[Table 8 here]

The FGT indicators are estimated and compared with the base case and their percentage changes from the base case are reported in Table 8. Positive change of FGT index denotes an increment in absolute poverty. As can be seen from this table under the base year simulation and simulation without adaptation, the poverty headcount ratios have increased significantly among all household groups. Simulation 3 of each climate change impact scenario shows how land re-allocation towards less impacted crops by climate change, such as paddy, can reduce the poverty headcount ratio. Comparing simulations 1 and 3 reveal that the poverty headcount ratios have decreased significantly among all household groups.

As evidenced from above, land re-allocation to climate-smart crops in Nepal is expected to improve the climate change—induced productivity losses and negative impacts on the overall economy. These improvements spread to sectors beyond the agriculture-related industries, such as manufacturing and services. As Nepalese manufacturing and service sectors are linked with agricultural products, a small improvement in agricultural productivity creates multiplier effects in the overall economy. Table 5 also predicts that manufacturing outputs in highest climate change impact scenario will decrease by around 10% due to crop productivity loss when normal land allocation prevails. However, a significant increase in output can be expected after land re-allocation. A similar situation is expected in the utility and services sectors if farmers keep allocating more land to climate-smart crops. This overall improvement has decreased the poverty level among all households groups.

4. Conclusions

Using a country-specific CGE model of the Nepalese economy, this paper has explored the macro- and micro-economic effects of climate-change impacts and land re-allocation in Nepalese agriculture. As mentioned in the results section, the simulation results of this study revealed that Nepalese agriculture will have severe impacts if land re-allocation is not trialled and implemented in the future. If the trend of allocating land to crops that suffer huge impacts from climate change continues, the resulting massive increase in commodity prices will pose great challenges for rural smallholders' livelihoods. As an outcome of these results, real GDP is expected to decrease markedly.

The results of this study are highly consistent with the results of previous studies. As Nepalese agriculture is the most affected among South Asian countries–according to Bandara and Cai (2014) and Chalise et al. (2017), among others–the results of the simulation described above show that climate-induced reduction in food production is projected to put an upward pressure on food prices, resulting in a food security problem in Nepal. The prices of rice, wheat and cereal grains—three major staple foods in Nepal—are expected to rise significantly at the rate of around 26%, 36% and 44% per annum respectively. As Nepal imports most of its staples foods from South Asian countries, the situation will become challenging as global food prices are expected to increase significantly in the future (FAO, 2015; Hertel et al., 2010).

Some key policy implications related to climate change, particularly from a larger perspective, can be drawn from this study. Nepal, as a member of the least-developed countries, can expect the impacts of climate change to be severe. Mainly because of its static adaptation capacity,[4] the vulnerability projection according to the A2 emission scenario in 2050 (IPCC, 2000) places Nepal in the significantly vulnerable category. Although farmers have already initiated some useful adaptation practices on their own, without any support from government or any other organisations, it is urgent to initiate large-scale planned strategies to support them. Based on the results of this study, as well as the likelihood of more frequent flash floods in low-land paddy farms and serious landslides in hilly maize farms in Nepal, it seems wise to invest more in controlling excess water flows and on forest management technology. In addition, serious consideration should be given to measures designed to prevent, mitigate and adapt to water deficiency in Nepalese cropping agriculture. As Salami, Shahnooshi, and Thomson (2009) suggest, cropping rotation and changes in the cropping-calendar, such as fairly simple modifications in vegetable growing (changed planting dates, and different maturity-date cultivars), can reduce likely climate change—induced losses in future decades.

To conclude, future research is recommended to address the limitations of this study. Our study has not explored the bio-physical aspects of climate-change impacts in detail, including

[4] According to the vulnerability projection report, vulnerability is a function of exposure, sensitivity and adaptive capacity.

those determining the actual cost of damage to crops and human capital, such as impacts in bio-physical requirements due directly or indirectly to imbalances in water, or to labour productivity, etc. Therefore, a study to evaluate all the factors responsible for productivity loss due to climate change, and the adaptation practices that have been started in Nepal, is required. A numerical assessment of the impacts and possible adaptation to climate change would require a much expanded modelling framework, and/or considered assumptions of the extent and distribution of such problems. Despite this study's limitations, its results have evidenced that serious policy planning and implementation of adaptation strategies in the near future is required to help reduce the negative impact of climate change on agriculture and to reduce the level of poverty among all household groups.

Appendix A

Table 1
Comprehensive literature survey on climate-change impacts in Nepalese agriculture

Source	Methodology	Crop	Productivity change (%)		
Kumar and Parikh (2001)	Regression on net farm revenue	All	-8.4 (Projection in Indian crops- as of +2°C)		
Cline (2007)	Integrating all models	All	Without carbon fertilisation = -17.3 With carbon fertilisation and adaptation = -4.8		
Iglesias and Rosensweig (2010)	Crop simulations on the basis of carbon dioxide emission scenarios[5]		2020	2050	2080
		Rice	-2.23	+2.70	+6.67
		Wheat	-7.55	+9.58	+9.37
		Maize	-7.75	-10.91	-4.98
Hertel et al. (2010)	General equilibrium analysis based on GTAP		Low	Medium	High
		Rice	-15	-5	+4
		Wheat	-10	-3	+4
		Maize	-17	-10	-3
Joshi et al. (2011)	Time Series Regression (1977-2008 as of +2°C)	Rice	+1.7		
		Wheat	+2.32		
		Maize	+1.49		
Knox et al. (2011)	Crop models		2020	2050	2080
		Rice	-2		-32
		Wheat		-60 (Indian crops)	
		Maize	+10 (other SA countries)		
Bandara and Cai (2014)	Systematic literature review on all models	Rice	-2		
		Wheat	-13.7		
		Maize	-17 (2030 projection)		

Note: This table is mainly based on a systematic literature survey and is adapted from Chalise et al. (2017)

[5] The data are available for different CO_2 emission scenarios of SRES (IPCC, 2000). The A2 scenario is employed for this study.

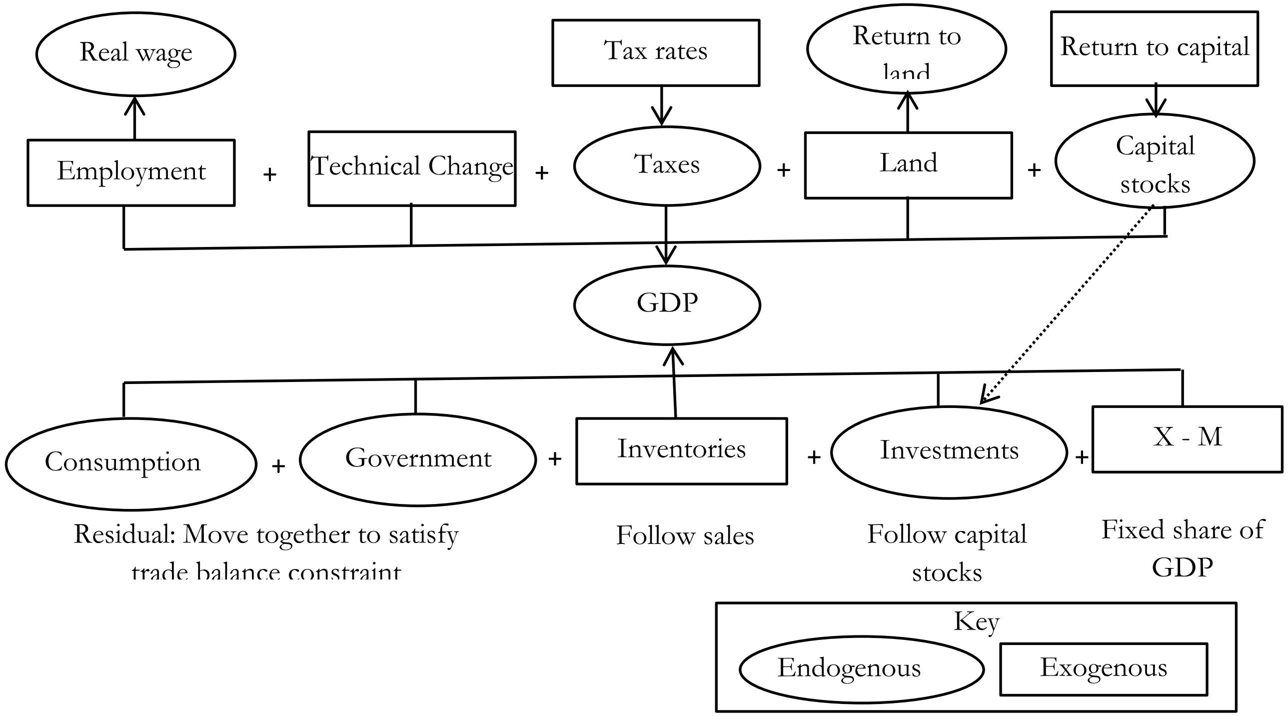


Diagram 1. Long-run closure used in the model.

Note: The exogenous and endogenous variables used in this model closure are based on recent ORANI-G version. *Source:* Chalise et al. (2017)

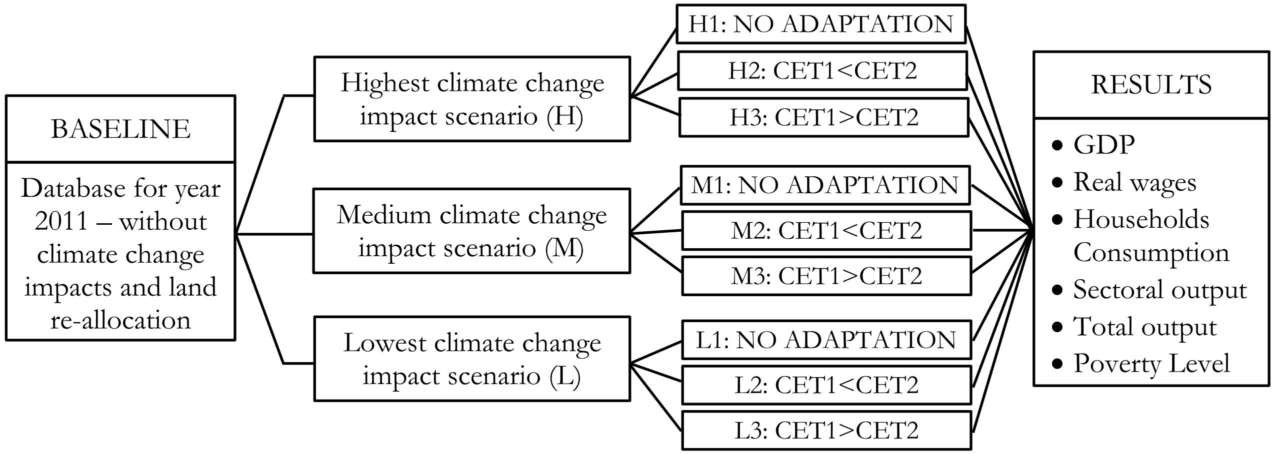


Diagram 2. Conceptual framework of the experiment *Note:* H1, H2, H3, M1, M2, M3, L1, L2 and L3 are simulations.

Table 2
Climate change induced productivity shocks used in the model (%)

Sector	Highest climate change impact scenario (H)	Medium climate change impact scenario (M)	Lowest climate change impact scenario (L)
Paddy Rice	-14.10%	-10.81%	-1.20%
Wheat	-18.90%	-14.16%	-2.30%
Maize	-24.70%	-19.08%	-6.90%
Other agricultural sectors	-19.30%	-14.67%	-4.80%

Note: This table is mainly based on a systematic literature survey and is based on Table 1.

Table 3
Estimation of base year (2011) poverty lines for seven different household groups

Household Groups	Poverty Lines (NPR)		
	Food	Non-Food	Overall
Rural land less	10600	5396	15996
Rural land small	10998	6321	17319
Rural land medium	11257	6283	17540
Rural land large	12537	5891	18428
Urban low education	11805	7772	19577
Urban medium education	11743	9390	21133
Urban high education	12610	13623	26233

Note: This table is mainly based on the poverty lines estimated by Central Bureau of Statistics, Nepal (CBS, 2011a), and overall poverty lines are used for this study.

Table 4

Projections of percentage change in macro-variables under different climate change and land re-allocation scenarios

Macro-variables	Highest impact scenario (H)			Medium impact scenario (M)			Lowest impact scenario (L)		
	No adaptation (H1)	With adaptation CET1<CET2 (H2)	With adaptation CET1>CET2 (H3)	No adaptation (M1)	With adaptation CET1<CET2 (M2)	With adaptation CET1>CET2 (M3)	No adaptation (L1)	With adaptation CET1<CET2 (L2)	With adaptation CET1>CET2 (L3)
Real GDP	-10.92	-11.76	-9.66	-8.38	-8.99	-7.36	-2.55	-3.13	-1.78
Real wage	-14.36	-17.95	-10.25	-11.02	-13.31	-7.98	-3.37	-4.99	-1.07
Household consumption	-9.88	-10.11	-8.44	-7.61	-8.27	-6.98	-2.36	-3.18	-1.97
Gross production	-10.52	-15.71	-9.29	-8.08	-11.40	-7.12	-2.45	-3.61	-1.62
Consumer price index	8.78	26.93	5.32	6.57	17.87	4.46	1.74	4.51	-0.10

Table 5

Projections of percentage change in industry output of commodities under different climate change and land re-allocation scenarios

Sectors	Highest impact scenario (H)			Medium impact scenario (M)			Lowest impact scenario (L)		
	No adaptation	With adaptation		No adaptation	With adaptation		No adaptation	With adaptation	
	(H1)	CET1<CET2 (H2)	CET1>CET2 (H3)	(M1)	CET1<CET2 (M2)	CET1>CET2 (M3)	(L1)	CET1<CET2 (L2)	CET1>CET2 (L3)
Agriculture	-12.99	-14.30	-11.35	-10.08	-10.95	-9.00	-3.24	-4.04	-2.36
Mining	-13.96	-36.08	-12.08	-10.55	-24.52	-9.10	-2.95	-6.49	-1.48
Manufacture	-10.07	-16.89	-8.77	-7.72	-12.07	-6.67	-2.30	-3.64	-1.32
Utilities	-7.55	-7.84	-6.74	-5.76	-6.01	-5.22	-1.73	-2.12	-1.38
Services	-8.13	-10.17	--7.11	-6.19	-7.53	-5.62	-1.84	-2.46	-1.42

Table 6

Projections of percentage change in total household income under different climate change and land re-allocation scenarios

Sectors	Highest impact scenario (H)			Medium impact scenario (M)			Lowest impact scenario (L)		
	No adaptation	With adaptation		No adaptation	With adaptation		No adaptation	With adaptation	
	(H1)	CET1<CET2 (H2)	CET1>CET2 (H3)	(M1)	CET1<CET2 (M2)	CET1>CET2 (M3)	(L1)	CET1<CET2 (L2)	CET1>CET2 (L3)
Rural land less	-13.25	-13.53	-10.94	-10.20	-10.80	-8.69	-3.14	-3.71	-2.03
Rural land small	-11.64	-12.42	-8.21	-8.94	-9.45	-6.70	-2.77	-3.76	-1.12
Rural land medium	-11.02	-11.18	-8.84	-8.49	-8.74	-7.38	-2.65	-2.83	-1.90
Rural land large	-11.04	-11.94	-9.76	-8.53	-8.87	-8.17	-2.67	-2.82	-2.51
Urban low education	-15.17	-18.18	-11.74	-11.66	-13.60	-9.03	-3.56	-4.97	-1.56
Urban medium education	-15.25	-15.40	-12.65	-11.74	-11.89	-9.89	-3.61	-4.39	-2.22
Urban high education	-14.55	-14.67	-12.45	-11.22	-11.41	-9.89	-3.46	-3.82	-2.50

Table 7

Projections of percentage change in household consumption under different climate change and land re-allocation scenarios

Sectors	Highest impact scenario (H)			Medium impact scenario (M)			Lowest impact scenario (L)		
	No adaptation (H1)	With adaptation		No adaptation (M1)	With adaptation		No adaptation (L1)	With adaptation	
		CET1<CET2 (H2)	CET1>CET2 (H3)		CET1<CET2 (M2)	CET1>CET2 (M3)		CET1<CET2 (L2)	CET1>CET2 (L3)
Rural land less	-9.73	-10.34	-8.72	-7.49	-8.78	-7.17	-2.32	-2.97	-2.17
Rural land small	-8.09	-9.20	-5.95	-6.22	-7.13	-5.17	-1.94	-2.02	-1.25
Rural land medium	-7.46	-8.86	-6.60	-5.76	-6.65	-5.86	-1.83	-2.08	-1.67
Rural land large	-7.48	-8.44	-7.12	-5.80	-6.26	-5.66	-1.85	-2.03	-1.54
Urban low education	-11.69	-12.16	-9.51	-8.97	-9.16	-7.52	-2.74	-3.24	-1.69
Urban medium education	-11.77	-12.31	-10.45	-9.06	-9.93	-8.39	-2.79	-2.93	-2.35
Urban high education	-11.05	-11.72	-10.24	-8.53	-9.09	-8.39	-2.64	-2.89	-2.45

Table 8

Projections of household poverty under different climate change and land re-allocation scenarios (unit = % of household below poverty line)

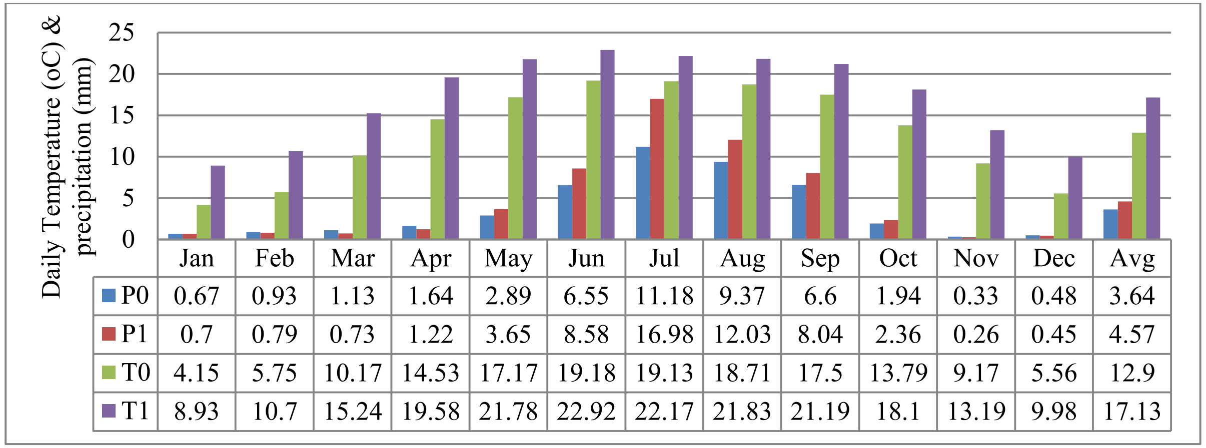
Households	Base	Highest impact scenario (H)			Medium impact scenario (M)			Lowest impact scenario (L)		
	No Climate Change	No adaptation	With Adaptation		No adaptation	With adaptation		No adaptation	With adaptation	
			CET1<CET2	CET1>CET2		CET1<CET2	CET1>CET2		CET1<CET2	CET1>CET2
Rural land less										
Head count ratio (α = 0)	29.67	38.02	45.27	35.38	35.38	40.00	32.83	31.64	32.74	30.98
Poverty gap (α = 1)	10.01	15.23	18.27	13.80	13.80	16.02	13.01	11.30	12.04	10.70
Poverty severity (α = 2)	4.01	7.39	10.25	7.00	7.10	8.40	6.50	5.40	5.80	5.10
Rural land small										
Head count ratio (α = 0)	50.98	62.09	68.30	58.08	58.98	63.80	56.78	53.10	55.22	51.71
Poverty gap (α = 1)	21.90	28.40	33.90	26.20	26.70	30.30	25.30	23.20	24.30	22.20
Poverty severity (α = 2)	12.30	16.70	20.80	15.20	15.60	18.10	14.60	13.20	14.02	12.50
Rural land medium										
Head count ratio (α = 0)	49.75	58.61	64.02	56.58	56.76	60.02	55.28	51.96	53.13	50.61

Poverty gap (α = 1)	22.30	28.20	32.07	26.66	26.76	29.24	25.81	23.61	24.43	22.88
Poverty severity (α = 2)	12.90	17.08	19.93	15.94	16.02	17.83	15.34	13.80	14.36	13.29
Rural land large										
Head count ratio (α = 0)	37.79	46.41	51.67	43.06	43.06	46.88	42.58	39.23	40.19	38.75
Poverty gap (α = 1)	16.69	21.20	23.75	20.20	20.05	21.65	19.51	17.64	18.15	17.21
Poverty severity (α = 2)	9.96	12.97	14.67	12.29	12.19	13.27	11.82	10.58	10.91	10.30
Urban low education										
Head count ratio (α = 0)	27.62	39.18	48.04	36.66	37.01	41.44	34.40	29.80	32.49	28.14
Poverty gap (α = 1)	11.86	16.72	21.35	15.22	15.36	18.14	14.34	12.75	13.50	12.10
Poverty severity (α = 2)	6.69	9.69	12.68	8.78	8.86	10.60	8.24	7.26	7.73	6.85
Urban med. education										
Head count ratio (α = 0)	11.26	18.87	28.16	17.18	16.90	22.25	15.40	12.11	13.23	11.26
Poverty gap (α = 1)	4.49	6.77	9.25	6.10	6.07	7.31	5.65	4.86	5.12	4.63
Poverty severity (α = 2)	2.49	3.71	4.86	3.38	3.36	3.98	3.15	2.72	2.87	2.58
Urban high education										
Head count ratio (α = 0)	5.43	10.04	12.97	7.11	7.11	10.46	7.11	5.85	6.27	5.43
Poverty gap (α = 1)	2.32	3.30	4.30	3.02	2.99	3.50	2.84	2.49	2.60	2.40
Poverty severity (α = 2)	1.40	1.93	2.37	1.80	1.78	2.02	1.70	1.50	1.56	1.45

Note: The poverty lines for each household and each simulation (base year poverty line for rural household = averagely NRs 92738/year and base year poverty line for urban households = averagely NRs 120995/year) are determined on the basis of the poverty report prepared by central bureau of statistics, Nepal (CBS, 2011a) and changes in consumer price index (CPI) reported in Table 4.

Appendix B

Figure B1 Projection of change in daily temperature and precipitation (1999 to 2080)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
P0	0.67	0.93	1.13	1.64	2.89	6.55	11.18	9.37	6.6	1.94	0.33	0.48	3.64
P1	0.7	0.79	0.73	1.22	3.65	8.58	16.98	12.03	8.04	2.36	0.26	0.45	4.57
T0	4.15	5.75	10.17	14.53	17.17	19.18	19.13	18.71	17.5	13.79	9.17	5.56	12.9
T1	8.93	10.7	15.24	19.58	21.78	22.92	22.17	21.83	21.19	18.1	13.19	9.98	17.13

Note: The Figure is mainly based on projection by Cline (2007). P0 = daily precipitation of base year-1999, P1 = projected daily precipitation of 2080, T0 = temperature of base year-1999 and T1 = projected temperature of 2080.

Appendix C

Table C1 Household groups and occupation types

Grouping	Household groups and their characteristics
Households	1. Rural landless households (no agricultural land) 2. Rural land small households (less than 0.5 Bigha*) 3. Rural land medium households (between 0.51 and 2.50 Bigha) 4. Rural land large households (more than 2.51 Bigha) 5. Urban low education (household head having less than class/grade 10 education) 6. Urban medium education (household head having both secondary school certificate and higher secondary certificate) 7. Urban high education (household head having bachelor and high degrees)

Occupations	1. Self-employed labours 2. High skilled professionals and managers 3. Medium skilled professionals and technicians 4. Government and non-government office clerks (employees) 5. Workers (transport, mechanics and other industrial workers) 6. Artisans and handicraftsmen 7. Informal (street-vendors and non-economic services nes) 8. Agricultural owners/administrators 9. Agricultural workers 10. Agriculture subsistence farmers

Note: Bigha* is a unit of land mostly used in the rural part of Nepal. One Bigha = 0.16055846 Hectares. This table is adapted from Chalise et al. (2017)

Appendix D

Table D1 List of industries

Sectors	Industries
Agriculture	1. Paddy rice 2. Wheat 3. Cereal grains nec 4. Vegetables, fruit and nuts 5. Oil seeds 6. Sugar cane, sugar beet 7. Plant-based fibers 8. Crops nec 9. Bovine cattle, sheep and goats, horses 10. Animal products nec 11. Raw milk 12. Wool, silk-worm cocoons 13. Forestry 14. Fishing
Mining	15. Coal 16. Oil 17. Gas 18. Minerals nec
Manufacturing	19. Bovine cattle, sheep and goat, horse meat products 20. Meat products nec 21. Vegetable oils and fats 22. Dairy products 23. Processed rice 24. Sugar 25. Food products nec 26. Beverages and tobacco products 27. Textiles 28 Wearing apparel 29. Leather products 30. Wood products 31. Paper products, publishing 32. Petroleum, coal products 33. Chemical, rubber, plastic products 34. Mineral products nec 35. Ferrous metals 36 Metals nec 37. Metal products 38. Motor vehicles and parts 39. Tranport equipment nec 40. Electronic equipment 41. Machinery and equipment nec 42. Manufacturers nec
Utilities	43. Electricity 44. Gas manufacture, distribution 45. Water
Services	46. Construction 47. Trade 48. Transport nec 49. Water transport 50. Air transport 51. Communication 52. Financial services nec 53. Insurance 54. Business services nec 55. Recreational and other services 56. Public administration and defense, education, health 57. Dwellings

Note: This Table is based on global trade analysis project (GTAP) database for the base year- 2011 *Source:* Aguiar, Narayanan, and McDougall (2016).

Appendix E

Equation E Land re-allocation equations used in the model

$$Y = \alpha\left[\sum_{i=1}^{n} \delta_i X_i^{\rho}\right]^{1/\rho} \quad \text{(E1)}$$

Where, δ = share of land and δ>0
α *and* ρ= parameter and ρ >1
x_i= land allocation for *i =1* to '*n*' crops

Objective function: $Max\ TR = \sum_{i=1}^{n} P_i X_i$

The Lagrangian equation for the above problem can be set up as follows:

$$L = \sum_{i=1}^{n} P_i X_i + \Lambda\left[Y - \left(\sum_{i=1}^{n} \delta_i X_i^{\rho}\right)^{\frac{1}{\rho}}\right] \quad \text{(E2)}$$

The first order conditions are as follows:

$$\frac{\partial L}{\partial X_k} = P_k - \Lambda\left(\sum_{i=1}^{n} \delta_i X_i^{\rho}\right)^{\frac{(1-\rho)}{\rho}} \delta_k X_k^{(\rho-1)} \quad \text{(E3)}$$

Where, *i = 1,…2,…..3,…..k,……*to *n* industries

$$\frac{\partial L}{\partial \Lambda} = Y - \left(\sum_{i=1}^{n} \delta_i X_i^{\rho}\right)^{\frac{1}{\rho}} \quad \text{(E4)}$$

Since,

$$\frac{\partial Y}{\partial X_k} = \left(\sum_{i=1}^{n} \delta_i X_i^{\rho}\right)^{\frac{(1-\rho)}{\rho}} \delta_k X_k^{(\rho-1)} \quad \text{(E5)}$$

$$P_k = \Lambda \frac{\partial Y}{\partial X_k} = \Lambda\left(\sum_{i=1}^{n} \delta_i X_i^{\rho}\right)^{\frac{1-\rho}{\rho}} \delta_k X_k^{(\rho-1)} \quad \text{(E6)}$$

Hence,

$$\frac{P_k}{P_i} = \frac{\Lambda\left(\sum_{i=1}^{n}\delta_i X_i^{\rho}\right)^{\frac{1-\rho}{\rho}}\delta_k X_k^{(\rho-1)}}{\Lambda\left(\sum_{i=1}^{n}\delta_i X_i^{\rho}\right)^{\frac{1-\rho}{\rho}}\delta_i X_i^{(\rho-1)}} \qquad \text{(E7)}$$

Or

$$\frac{P_k}{P_i} = \frac{\delta_k}{\delta_i}\left(\frac{X_k}{X_i}\right)^{(1-\rho)} \qquad \text{(E8)}$$

By rearranging the above equation, we could obtain an equation for X_i^{ρ} as follows:

$$X_i^{(1+\rho)} = \frac{P_i\delta_k}{P_k\delta_i} \cdot X_k^{(1+\rho)} \qquad \text{(E9)}$$

$$X_i^{\rho} = \left(\frac{P_i\delta_k}{P_k\delta_i}\right)^{\left(\frac{\rho}{\rho-1}\right)} . X_k^{\rho} \qquad \text{(E10)}$$

Using the CET function given by equation (E1) and substituting the equation (E10) back into the CET function, we obtain:

$$Y = X_k\left\{\sum_{i=1}^{n}\delta_i\left(\frac{P_i\delta_k}{P_k\delta_i}\right)^{\frac{\rho}{(\rho-1)}}\right\}^{\frac{1}{\rho}} \qquad \text{(E11)}$$

By rearranging equation (12), we can obtain the factor supply function as:

$$X_k = \frac{Y}{\left\{\sum_{i=1}^{n}\delta_i\left(\frac{P_k\delta_i}{P_i\delta_k}\right)^{\frac{\rho}{(\rho-1)}}\right\}^{\frac{1}{\rho}}} \qquad \text{(E12)}$$

Or

$$X_k = Y\left\{\sum_{i=1}^{n}\delta_i\left(\frac{P_i\delta_k}{P_k\delta_i}\right)^{\frac{\rho}{(\rho-1)}}\right\}^{-\frac{1}{\rho}} \qquad \text{(E13)}$$

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