

# **Climate Change Adaptation in Agriculture: A General Equilibrium Analysis of Land Re-Allocation in Nepal**

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## **ABSTRACT**

This paper investigates the viability of cropland re-allocation as an adaptation strategy to minimise the economy-wide costs of climate change on agriculture. Nepal makes an interesting case study as it is one of the most vulnerable agricultural economies within South Asia. We develop a comparative static multi-household 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. Land transformation elasticities in these CET functions are allowed to reflect the ease of switching from one crop to another based on their agronomic characteristics. The results suggest that, in the long run, farmers in Nepal tend to allocate land to crops that are comparatively less impacted by climate change, such as paddy, thereby minimising the economy-wide impacts of climate change. Furthermore, the results reveal that land re-allocation tends to reduce the income disparity between different household groups by significantly moderating the income losses of marginal farmers. Therefore, it is suggested that policy makers in Nepal should prioritise schemes such as providing climate-smart paddy varieties (i.e., those that are resistant to heat, drought and floods) to farmers, subsidising fertilizers, improving agronomic practices, and educating farmers to switch from crops that are highly impacted by climate change to those that are not, such as paddy.

**Keywords:** Climate change; general equilibrium; land re-allocation; Nepalese agriculture

## **1. Introduction**

A significantly growing body of literature on climate change has a common understanding on two major issues. First, given the importance of agriculture to employment and people's livelihoods in developing countries such as Nepal, the loss of agricultural productivity due to climate change is of great social and economic concern. Many socio-economic sectors besides agricultural value chains are also likely to experience indirect effects of discrepancies in income and consumption. As a consequence of these threats, climate change imposes additional stresses to the social and economic challenges that the poorest already face (IPCC, 2013), highlighting and accelerating their vulnerabilities, as their livelihoods depend on already overstrained climate-sensitive resources and their social welfare systems are weak. By directly depleting the agricultural resources that poor people depend on for their livelihoods, climate change increases their chances of falling into a cycle of poverty from which it is difficult to escape. 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, it is likely that farmers will implement harmful practices in the long term.

Second, 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 (Claessens et al., 2012; Esham & Garforth, 2013).

Gradually re-allocating land from high-impact crops to low-impact ones is one of the best adaptation options that farmers in Nepal have been experimenting with to minimize 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 maximize 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, significant challenges facing the farmers in developing countries are to understand the actual agronomic feasibility of switching crops and to experiment with land re-allocation practices that maximise farm revenue as well as food security. In this sense, a study on assessing the impacts of climate change and the benefits of the land re-allocation is important in the current 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 emphasize 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.

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; 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.

Among the specification parameters affecting the quantitative and qualitative results of these CGE models, substitution and transformation elasticity of primary factors for various uses have a major influence (Palatnik et al., 2011). Several CGE models have used functions such as constant elasticity of substitution (CES) and constant elasticity of transformation (CET) for this purpose. The original ORANI-G model (Dixon, Parmenter, Sutton, & Vincent, 1982) also uses a CES function as a factor composite for production, assuming a significant elastic CES sub-set for labour among several occupational skill groups. Such models assume that land is fixed for an industry, which we argue is extremely likely to result in over- or under- estimation of climate-change impacts due to the exclusion of land-transformation possibilities among crops. In developing countries, individual farmers and households operating at the micro-level make most of the land-use decisions to adapt to the threats of climate change. Therefore, in this paper, we attempt to model and assess individual decisions regarding land re-allocation among different industries in a more mathematical way.

We propose a simple model, based on the Nepalese economy that provides a general framework for allowing climate-change impacts and adaptation strategies to be tested. 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 allocation for several crops.

Although recent studies (e.g., Fujimori, Hasegawa, Masui, & Takahashi, 2014; Hertel, Burke, & Lobell, 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 model parameters. Second, these studies have not tested the possibility of crop switching with a range of CET values. This has created a serious gap in the policy recommendations, in which the implication of such beneficial land-use to local farmers is missing.

Therefore, the main objective of this paper is to modify the widely used assumption of “fixed land supply for a given industry”, 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 of climate change-induced agricultural loss both “with” and “without” land re-allocation. The rest of the paper is organized as follows: Section 2 justifies the rationale of selecting Nepal as a case study, including a literature survey on climate-change impacts on Nepalese agriculture; Section 3 illustrates the methodology, including the empirical model and framework; Section 4 depicts the simulation results; and Section 5 offers some short policy discussion and conclusions.

## **2. Why Nepal as a case study? Motivation and literature review**

We have purposefully chosen Nepalese agriculture to illustrate the economy-wide impacts of re-allocating land as adaptation strategy to climate change for a number of reasons. First,

the agricultural sector plays a vital role in the economy of Nepal, particularly in the rural sector. Around 80% of Nepalese households are located in rural farms or regional areas, but only 50% of their income is generated from agricultural sources (World Bank, 2012), which is insufficient to provide a secure livelihood. Although the contribution of agriculture to the national GDP has been decreasing during recent years—from more than 50% in 1995 to about 35% in 2011/12 (CBS, 2014)—it is still one of the highest among South Asian countries. The agrarian societies in Nepal, who live primarily in rural areas, have the strongest bond with the ecosystems that are sensitive to climate changes. Besides agriculture, the livelihood of the rural population is closely linked to the forest, another climate-sensitive sector. More than 86% of the energy needs of the population are met by firewood, agricultural residue and animal wastes (CBS, 2014).

Second, due to the country's steep rugged topography, Nepalese agriculture is one of the most vulnerable sectors to climate change in South Asia (Bandara & Cai, 2014; Chalise, Maraseni, & Maroulis, 2015). Limited arable lands, a rain-fed farming system and fragile land constructs result in frequent natural disasters. With regard to the climate-change parameters in Nepal, the regional climate-model projections show temperature increases of 1.6°C–2.0°C by 2030, 2.3°C–2.9°C by 2050, and 3.4°C–5.0°C by 2080 (Ahmed & Suphachalasai, 2014). These increases in temperature are likely to result in erratic precipitation, greater soil erosion and droughts in the future. Moreover, prolonged droughts could result in rapid evaporation and ultimately the drying of important water bodies in the mid-eastern parts of Nepal (Chalise et al., 2015; Gurung & Bhandari, 2009), which would cause extreme starvation among the poor.

Third, Nepal has relatively low per capita income of USD 562 (CBS, 2014) and, therefore, has been categorised as a least-developed country by the World Bank and other international organisations. Nearly 25% of the population in Nepal live below the poverty line based on the

well-known USD 1.25 per day poverty measurement. Hence, any adverse impacts on Nepalese agriculture as a result of climate change could be disastrous for those living below the poverty line, subsistence farmers in particular, as well as for the national economy in general. Consequently, Nepalese farmers are more vulnerable to climate-change impacts than farmers in more progressive countries, since they already have insufficient resources to confront the many evolving climate-change challenges.

Table 1 summarises a comprehensive literature 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 fertilization strategies are implemented and the rate of current technological growth continues.

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 et al. (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<sup>1</sup> (e.g., Auffhammer, Ramanathan, & Vincent, 2012; Byjesh, Kumar, & Aggarwal, 2010; Kumar, 2011; Kumar & Parikh, 2001) have predicted a range of significant

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<sup>1</sup> 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).

productivity loss in Indian agriculture. Overall, some literature expects notably positive impacts 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, an average of these estimations can be used as inputs for our modelling analysis, as described in the next section.

**Table 1**

Comprehensive literature survey on climate-change impacts in Nepalese agriculture

Source	Methodology	Crop	Productivity Change (%)			Average
Kumar and Parikh (2001)	Regression on net farm revenue	All	-8.4 (Projection in Indian crops- as of +2°C)			Paddy = -10.81 Wheat = -14.16 Maize = -19.08 Other agricultural sectors = -14.67
Cline (2007)	Integrating models	all	All	Without carbon fertilization = -17.3 With carbon fertilization and adaptation = -4.8		
Iglesias and Rosensweig (2010)	Crop simulations on the basis of carbon dioxide emission scenarios <sup>2</sup>	Rice	<u>2020</u>	<u>2050</u>	<u>2080</u>	
		Wheat	-2.23	+2.70	+6.67	
		Maize	-7.55	+9.58	+9.37	
			-7.75	-10.91	-4.98	
Hertel et al. (2010)	General equilibrium analysis based on GTAP	Rice	<u>Low</u>	<u>Medium</u>	<u>High</u>	
		Wheat	-15	-5	+4	
		Maize	-10	-3	+4	
			-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	Rice	<u>2020</u>	<u>2050</u>	<u>2080</u>	
		Wheat	-2		-32	
		Maize	-60 (Indian crops)			
			+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

<sup>2</sup> The data are available for different CO<sub>2</sub> emission scenarios of SRES (IPCC, 2000). A2 scenario, characterized by a world of independently operating, self-reliant nations, continuously increasing population and regionally oriented economic development, is employed for this study.



### **3. Empirical model and framework**

On the one hand, it is not hard to comprehend the qualitative impacts of climate change when household economic parameters are not included. On the other hand, when quantifying climate-change impacts and possible adaptation strategies, including households' economic parameters, it is difficult to assess the effects of all factors that are responsible for climate change. CGE models have frequently been used to model the behaviour and decisions of households. However, the recent trend of using 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 in agriculture has created a substantial literature gap in assessing possible adaptations. 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 due to climate-change-induced changes in agriculture.

#### **3.1. Theoretical Framework**

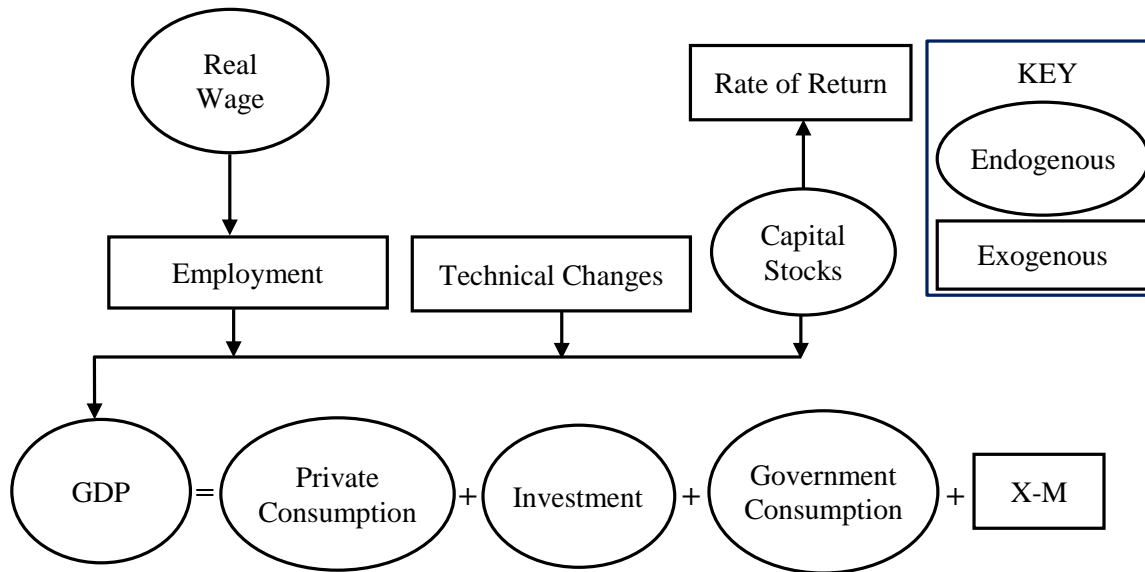
This paper uses a comparative-static CGE model, following the tradition of the applied general equilibrium approach pioneered by Dixon et al. (1982), although its precise specification is more closely related to the South African CGE model developed by Horridge et al. (1995). As in any generic CGE model, producers are assumed to maximise profits subjected to resource constraints and consumers are assumed to maximise utility subject to budget constraints. Moreover, this model also follows the neoclassical 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.

For the purpose of simulation, this model consists of 57 industries, 57 commodities, 3 factors, 7 household groups and 10 skill/occupations type (see Appendix B and C). 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 CES functions for specifying production technologies and consumer demands for final goods and services. Households, government, enterprises 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 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 B). 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, 2011) to disaggregate households' final consumption and returns from primary factors. Second, to allow for differential effects in the

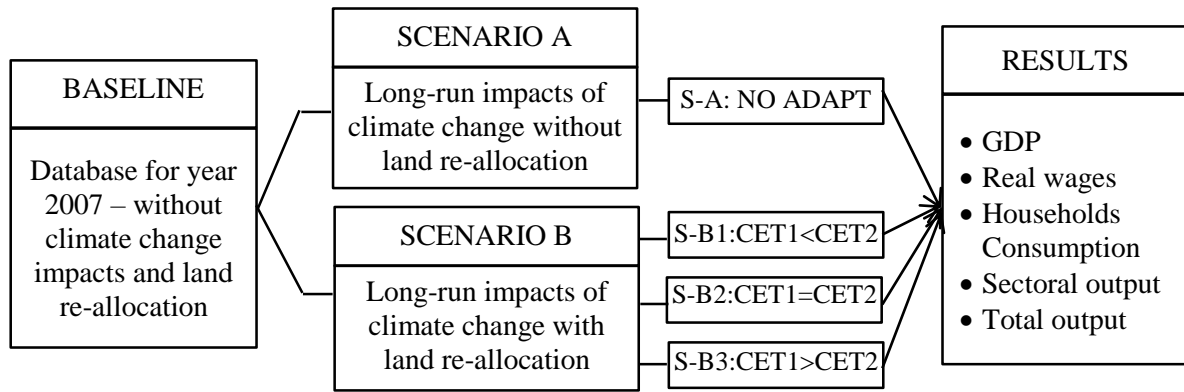
employment of skill categories, we introduce 10 occupation types and explicitly model the heterogeneity of levels of income.



**Diagram 1.** 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.

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 a country but completely immobile in the rest of the world. As there is a scientific consensus that the impacts of climate change can be realized 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, and to evade the dangers of disequilibrium in the neoclassical approach [such as the issue raised by Scricciu (2007)]. 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.



**Diagram 2.** Conceptual framework of the experiment *Note:* S = simulation

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 sectors<sup>3</sup> (out of the 57 sectors in the GTAP database— see Appendix C) in Nepal. From the impact assessment—related literature, an average productivity shocks of rice, wheat, maize and other agricultural products are employed in the CGE model developed for this study (Table 1). The reasons for taking an average 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. Two scenarios are developed for the simulations in this paper. Diagram 2 presents the conceptual framework. Scenario A assumes that normal land allocation prevails and there is no change in land supply with respect to impacts of climate change. Scenario B has three simulations, assuming that the land is mobile among industries. The first simulation

<sup>3</sup> They are 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.

assumes that the CET of paddy (CET1) is less than the CET of other agricultural sectors (CET2); the second that CET1 is equal to CET2; and the third that CET1 is greater than CET2 (the framework of nested CET parameters is discussed in the following section). 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.

### 3.2. 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,  $X_i$  ( $i = 1 \dots k \dots n$ ), to maximise the total returns from the inputs of producing a given output,  $Y$ , subject to the CET production function:

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

$$\text{and objective function: } \text{Max } TR = \sum_{i=1}^n P_i X_i \quad (2)$$

Where,  $\delta$  is share of land, and  $\delta > 0$ .  $\alpha$  and  $\rho$  are parameters, and  $\rho > 1$ .  $X_i$  is a plot of land allocated, for  $i$  is equal to 1 to 'n' crops.  $P_i$  is profit of an effective land unit.  $\delta_i$  and  $\rho$  are behavioural parameters and  $TR$  is the total revenue generated from the land. To solve the model in the level forms, the values of  $\delta_i$  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:

$$L = \sum_{i=1}^n P_i X_i + \Lambda \left[ Y - \left( \sum_{i=1}^n \delta_i X_i^\rho \right)^{\frac{1}{\rho}} \right] \quad (3)$$

From which (see Equation D4 to Equation D13 in Appendix D for the complete derivation), we have, for a particular industry,  $k$ :

$$X_k = Y \left\{ \sum_{i=1}^n \delta_i \left( \frac{P_i \delta_k}{P_k \delta_i} \right)^{\frac{\rho}{\rho-1}} \right\}^{-\frac{1}{\rho}} \quad (4)$$

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

$$x_k = z - \sigma (p_{ave} - p_k) \quad (5)$$

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.  $\sigma$  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 5),  $\sigma$  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  $\sigma$  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  $\sigma$ , 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 5 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 both the positive and negative 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.

#### 4. Effects of land re-allocation: simulation results

The results obtained from the simulations of the impacts of climate change and land re-allocation on Nepalese agriculture are analysed in two different stages: (1) changes in the overall macro-variables; and (2) impacts at the household level. As mentioned in the methodology 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 2007 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, four distinct climate change scenarios are simulated. In scenario A, the effects of climate change are analysed assuming that normal land allocation prevails and that the effects of land re-allocation among agricultural sectors can be ignored. In scenario B, 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 methodology section, scenario B is analysed with three different simulations on the basis of CET ratio: B1 has  $CET1 < CET2$ , B2 has  $CET1 = CET2$  and B3 has  $CET1 > CET2$  (CET value ranges from 0.5 to 20).

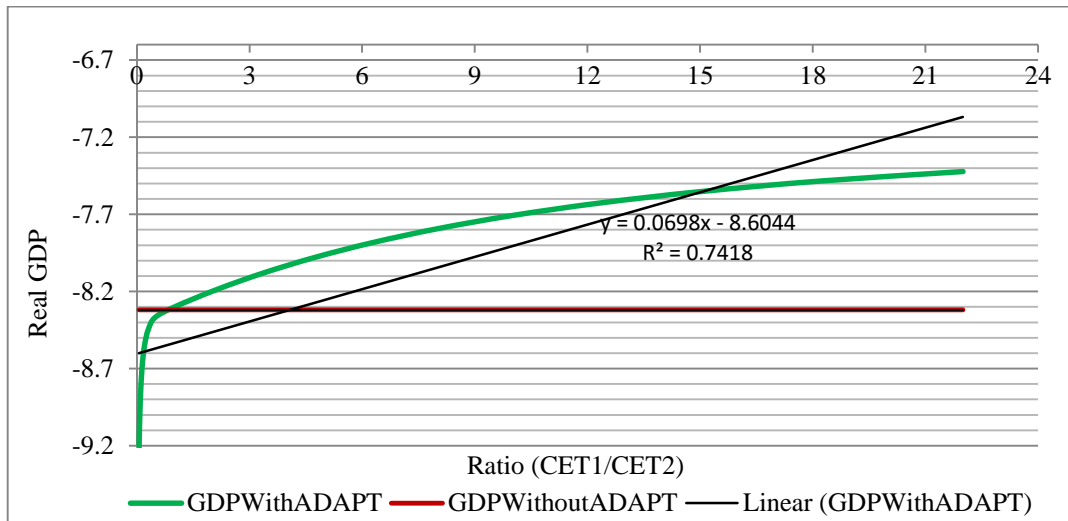
**Table 2**

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

Macro-variables	Simulation 1 Without climate change adaptation	Simulation 2 With climate change adaptation and $CET1 < CET2$	Simulation 3 With climate change adaptation and $CET1 = CET2$	Simulation 4 With climate change adaptation and $CET1 > CET2$
Real gross domestic product	-8.315	-11.042	-8.301	-7.067
Consumer price index	7.181	15.263	7.212	5.792
Real wage	-11.061	-17.839	-10.851	-7.585
Household consumption	-7.534	-7.841	-7.489	-6.740



Terms of trade	1.162	3.455	1.291	1.733
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**Figure. 1.** Trend of change in real GDP from baseline in Nepal with increasing CET ratio (CET1/CET2) as a result of climate change with and without land re-allocation (unit = %)

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 2 shows that, without land re-allocation, the projected impact of climate change on agricultural productivity affects real GDP negatively. In scenario A, the real GDP is expected to decrease by 8.31%. 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 scenario B, 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. As shown in Figure 1, an increasing trend of CET ratio (CET1:CET2) improves the real GDP. This is because a higher CET ratio means that farmers are able to allocate more land to paddy than to other agricultural sectors on the basis of the degree of climate-change impacts in these respective crops.

**Table 3**

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

Sectors	Simulation 1 Without climate change adaptation		Simulation 2 With climate change adaptation CET1<CET2		Simulation 3 With climate change adaptation CET1=CET2		Simulation 4 With climate change adaptation CET1>CET2	
	Output	Price	Output	Price	Output	Price	Output	Price
Agriculture	-9.872	20.956	-11.590	37.675	-9.799	20.896	-8.734	18.035
Mining	-1.859	-1.731	-9.925	4.556	-6.998	1.654	-6.201	1.793
Manufacture	-8.458	4.261	-12.933	6.106	-8.527	4.133	-7.731	2.626
Utilities	-6.631	-0.484	-9.898	1.661	-6.683	-0.343	-5.957	0.203
Services	-6.211	-0.986	-9.791	2.1938	-6.295	-0.785	-5.747	0.034

Overall outputs of other sectors are likely to be affected according to climate change—induced productivity loss in Nepalese agriculture. Table 3 shows the decrease in sectoral output and the improvement that can be achieved with land re-allocation. The manufacturing sector in particular is expected to be highly influenced by climate-change impacts, as this sector primarily depends on agricultural raw materials and products.

**Table 4**

Projections of percentage change in consumer price index (CPI) and household consumption of commodities under different climate change and land re-allocation scenarios

Households	Simulation 1 Without climate change adaptation		Simulation 2 With climate change adaptation CET1<CET2		Simulation 3 With climate change adaptation CET1=CET2		Simulation 4 With climate change adaptation CET1>CET2	
	CPI	CON	CPI	CON	CPI	CON	CPI	CON
Rural land less	7.18	-7.68	15.26	-8.05	7.21	-7.65	5.79	-6.98
Rural land small	7.17	6.33	15.22	-8.02	7.20	-6.23	5.78	-4.76
Rural land medium	7.17	-5.87	15.21	-4.68	7.19	-5.82	5.78	-5.48
Rural land large	7.17	-9.15	15.21	-2.91	7.20	-5.90	5.79	-6.33
Urban low education	7.18	-9.20	15.30	-12.42	7.21	-9.05	5.79	-7.32
Urban medium education	7.18	-9.20	15.30	-10.41	7.21	-9.15	5.80	-8.17
Urban high education	7.18	-8.63	15.28	-8.37	7.21	-8.62	5.80	-8.12

**Note:** CPI = consumer price index and CON = household consumption

As overall sectoral outputs decrease substantially due to climate change, commodity prices are expected to increase significantly. Table 3 shows the estimated increase in prices of agricultural and other commodities in both scenarios. As climate change has a huge impact on Nepalese agriculture, the results show a significant increase in the prices of agricultural commodities in particular; in fact, it would not be surprising if there were a huge crisis in agricultural products in the future. Moreover, although rice is a major part of agricultural economy in Nepal, cereal crops also play an important role in rural livelihoods, especially in the mid-hills and rural mountains (CBS, 2012). The expected increase in the price of cereal crops in Nepal will obviously create a huge food security problem in the future. Table 4 clearly depicts the impact of increased prices on the consumer price index for all household groups. However, if farmers are able to re-allocate land to paddy, the expected increase in price of commodities would slow down and reduce the risk of food insecurity.

A substantial decrease in sectoral outputs, primarily in agricultural products, influences household income and consumption. 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 2, 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 4 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

saving and consumption are projected to improve if farmers allocate land to paddy as expected.

**Table 5**

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

Households	Simulation 1		Simulation 2		Simulation 3		Simulation 4	
	Without climate change adaptation		With climate change adaptation		With climate change adaptation		With climate change adaptation	
	LI	TI	LI	TI	LI	TI	LI	TI
Rural land less	-5.71	-10.31	-5.65	-13.74	-5.48	-10.21	-3.51	-8.39
Rural land small	-2.09	-8.98	-1.01	-13.72	-1.83	-8.81	0.25	-6.19
Rural land medium	-1.38	-8.50	-0.07	-10.45	-1.11	-8.40	0.98	-6.90
Rural land large	-1.96	-8.52	-0.79	-8.712	-1.69	-8.48	0.37	-7.74
Urban low education	-5.51	-11.75	-5.43	-18.01	-5.29	-11.59	-3.31	-8.73
Urban medium education	-7.19	-11.80	-7.34	-16.04	-6.98	-11.69	-4.97	-9.57
Urban high education	-7.98	-11.25	-8.16	-14.04	-7.77	-11.16	-5.69	-9.52

*Note:* LI = labour income and TI = total household income

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 (see Table 6). As the cost of living goes up due to extreme inflationary prices, overall real wages decrease significantly. We have noted the huge decrease in sectoral output in manufacturing and services (see Table 3), labour income in urban households will decrease considerably, more so than in rural households. 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.

**Table 6**

Projections of percentage change in employment over different occupation groups under different climate change and land re-allocation scenarios

Occupations	Simulation 1 Without climate change adaptation	Simulation 2 With climate change adaptation CET1<CET2	Simulation 3 With climate change adaptation CET1=CET2	Simulation 4 With climate change adaptation CET1>CET2
Self employed	-3.61	-4.81	-3.68	-3.95
High skilled professionals	-4.41	-5.14	-4.43	-4.26
Medium skilled professionals	-3.23	-3.77	-3.25	-3.18
NGO/INGO clerks	-4.40	-4.90	-4.39	-4.08
Industry workers	1.02	0.78	1.01	1.04
Art and crafts	-2.91	-4.34	-3.00	-3.28
Informal workers	-0.87	-1.29	-0.87	-0.74
Agriculture owners	2.67	3.17	2.67	2.52
Agriculture workers	2.87	3.49	2.91	2.97
Agriculture subsistence farmers	7.24	9.17	7.31	7.38

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 3 also predicts that manufacturing outputs will decrease by around 8% 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.

## 5. Discussion and 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, p. 459), 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 staple 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,<sup>4</sup> 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

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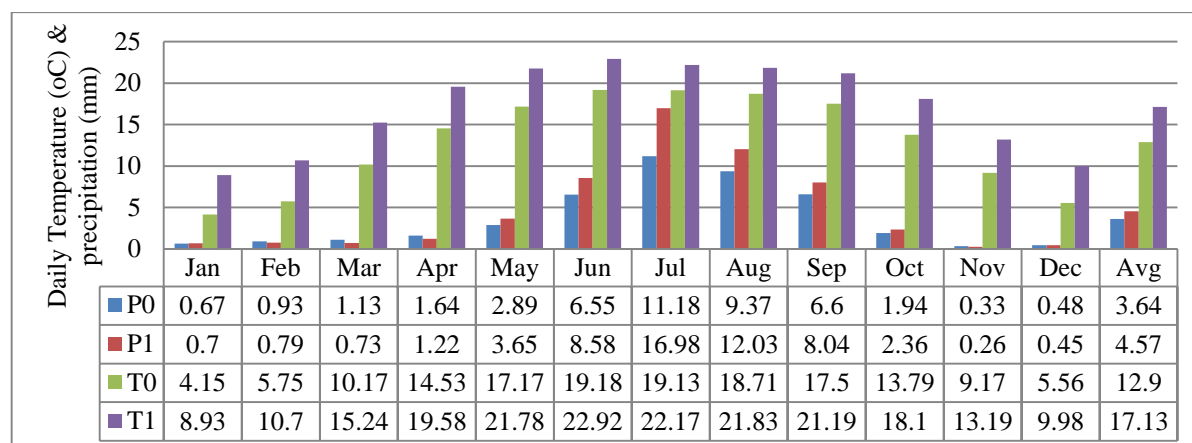
<sup>4</sup> According to the vulnerability projection report, vulnerability is a function of exposure, sensitivity and adaptive capacity.

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 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.

## Appendix A

**Figure A1** Projection of change in daily temperature and precipitation (1999 to 2080)



**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 B

**Table B1** Household groups and occupation types

Grouping	Income groups and their characteristics
Households	<ol style="list-style-type: none"> <li>1. Rural landless farmer</li> <li>2. Rural land small farmer (less than 0.5 Bigha*)</li> <li>3. Rural land medium farmer (between 0.51 and 2.50 Bigha)</li> <li>4. Rural land large farmer (more than 2.51 Bigha)</li> <li>5. Urban low education (household head having less than class/grade 10 education)</li> <li>6. Urban medium education (household head having both secondary school certificate and higher secondary certificate)</li> <li>7. Urban high education (household head having bachelor and high degrees)</li> </ol>
Occupations	<ol style="list-style-type: none"> <li>1. Self-employed labourers</li> <li>2. High skilled professionals and managers</li> <li>3. Medium skilled professionals and technicians</li> <li>4. Government and non-government office clerks (employees)</li> <li>5. Workers (transport, mechanics and other industrial workers)</li> <li>6. Artisans and handicraftsmen</li> <li>7. Informal (street-vendors and non-economic services nes)</li> <li>8. Agricultural owners/administrators</li> <li>9. Agricultural workers</li> <li>10. Agriculture subsistence farmers</li> </ol>

**Note:** Bigha\* is a unit of land mostly used in the rural part of Nepal. One Bigha = 0.16055846 Hectares.



## Appendix C

**Table C1** 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. Transport 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- 2007

## Appendix D

**Equation D** Land re-allocation equations used in the model

$$Y = \alpha [\sum_{i=1}^n \delta_i X_i^\rho]^{1/\rho} \quad (D1)$$

Where,  $\delta$  = share of land and  $\delta > 0$   
 $\alpha$  and  $\rho$  = parameter and  $\rho > 1$   
 $x_i$  = land allocation for  $i = 1$  to 'n' crops

$$\text{Objective function: } Max TR = \sum_{i=1}^n P_i X_i \quad (D2)$$

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

$$L = \sum_{i=1}^n P_i X_i + \Lambda \left[ Y - \left( \sum_{i=1}^n \delta_i X_i^\rho \right)^{\frac{1}{\rho}} \right] \quad (D3)$$

The first order conditions are as follows:

$$\frac{\partial L}{\partial X_k} = P_k - \Lambda \left( \sum_{i=1}^n \delta_i X_i^\rho \right)^{\frac{(1-\rho)}{\rho}} \delta_k X_k^{(\rho-1)} \quad (D4)$$

Where,  $i = 1, \dots, 2, \dots, 3, \dots, k, \dots, n$  industries

$$\frac{\partial L}{\partial \Lambda} = Y - \left( \sum_{i=1}^n \delta_i X_i^\rho \right)^{\frac{1}{\rho}} \quad (D5)$$

Since,

$$\frac{\partial Y}{\partial X_k} = \left( \sum_{i=1}^n \delta_i X_i^\rho \right)^{\frac{(1-\rho)}{\rho}} \delta_k X_k^{(\rho-1)} \quad (D6)$$

$$P_k = \Lambda \frac{\partial Y}{\partial X_k} = \Lambda \left( \sum_{i=1}^n \delta_i X_i^\rho \right)^{\frac{1-\rho}{\rho}} \delta_k X_k^{(\rho-1)} \quad (D7)$$

Hence,

$$\frac{P_k}{P_i} = \frac{\Lambda \left( \sum_{i=1}^n \delta_i X_i^\rho \right)^{\frac{1-\rho}{\rho}} \delta_k X_k^{(\rho-1)}}{\Lambda \left( \sum_{i=1}^n \delta_i X_i^\rho \right)^{\frac{1-\rho}{\rho}} \delta_i X_i^{(\rho-1)}} \quad (D8)$$

Or

$$\frac{P_k}{P_i} = \frac{\delta_k \left( \frac{X_k}{X_i} \right)^{(1-\rho)}}{\delta_i \left( \frac{X_k}{X_i} \right)} \quad (D9)$$

By rearranging the above equation, we could obtain an equation for  $X_i^\rho$  as follows:

$$X_i^{(1+\rho)} = \frac{P_i \delta_k}{P_k \delta_i} \cdot X_k^{(1+\rho)} \quad (D10)$$

$$X_i^\rho = \left( \frac{P_i \delta_k}{P_k \delta_i} \right)^{\left( \frac{\rho}{\rho-1} \right)} \cdot X_k^\rho \quad (D11)$$

Using the CET function given by equation (D1) and substituting the equation (D11) back into the CET function, we obtain:

$$Y = X_k \left\{ \sum_{i=1}^n \delta_i \left( \frac{P_i \delta_k}{P_k \delta_i} \right)^{\frac{\rho}{\rho-1}} \right\}^{\frac{1}{\rho}} \quad (D12)$$

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

$$X_k = \frac{Y}{\left\{ \sum_{i=1}^n \delta_i \left( \frac{P_i \delta_i}{P_i \delta_k} \right)^{\frac{\rho}{\rho-1}} \right\}^{\frac{1}{\rho}}} \quad (D13)$$

$$\text{Or, } X_k = Y \left\{ \sum_{i=1}^n \delta_i \left( \frac{P_i \delta_k}{P_k \delta_i} \right)^{\frac{\rho}{\rho-1}} \right\}^{-\frac{1}{\rho}} \quad (D14)$$

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