

# KILKHOR: Dynamic climate change based CGE model

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## Introduction

The original dynamic CGE model for Bhutan is described in Robichaud (2024b). In order to capture the impact climate change might have on the electricity sector, the original model was adapted to better reflect the way electricity generation differs between seasons.

As the dynamic CGE model for Bhutan is based on the PEP 1-1 and PEP-1-t model, this document draws largely on their documentations<sup>1</sup>. The Bhutanese model was built based on the social accounting matrix (SAM)<sup>2</sup> for 2017, which relies on the most recent supply and use tables produced by the National Statistics bureau of Bhutan.

The description of the model follows the order in which the equations are introduced in the GAMS code. The numbering also follows the GAMS code.

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<sup>1</sup> Decaluwé et al (2013), hereafter DLRM and DLRM2

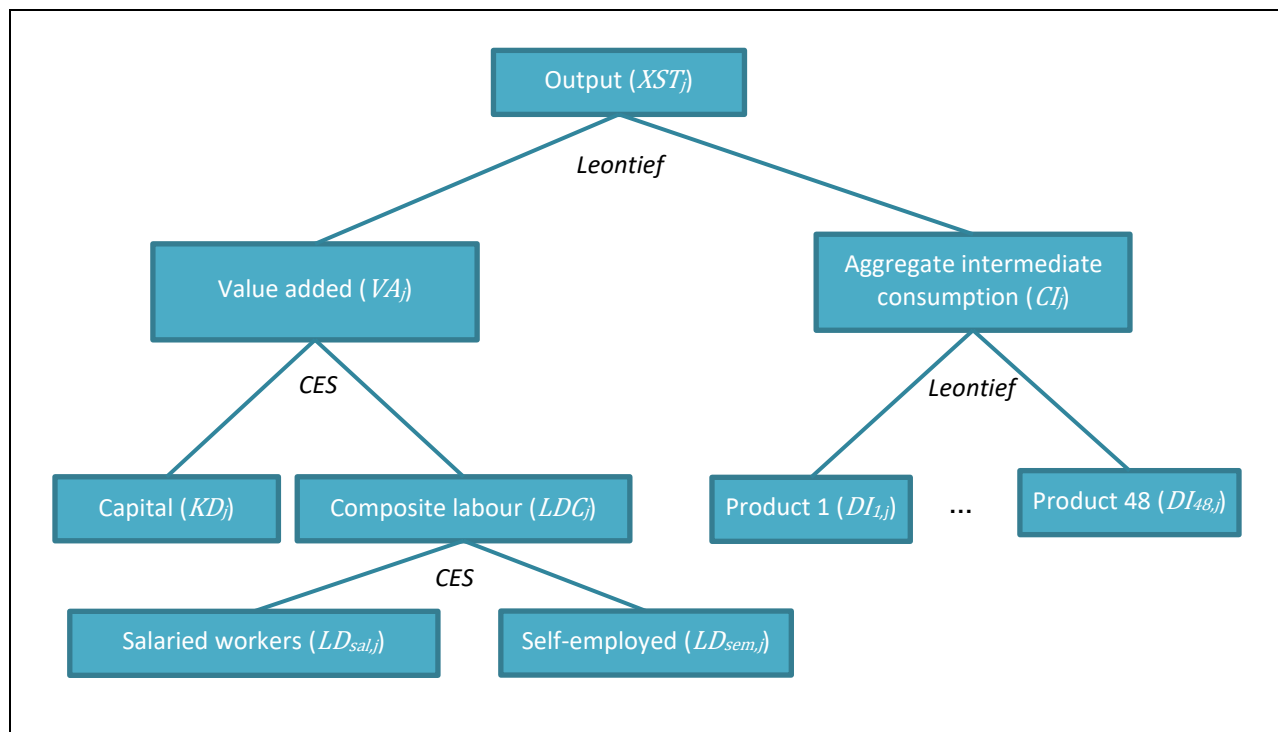
<sup>2</sup> Robichaud (2024a)

# 1. Production

Consistent with the supply and use tables 2017, the SAM of Bhutan considers 33 industries (see the list and description of industries in Appendix A) that represented by indices  $j, jj \in J = \{J_1, \dots, J_{33}\}$ .

Firms are assumed to operate in a perfectly competitive environment and they maximize their profits subject to their production technology and consider the prices of goods and services and factors of production as given (price-taking behavior). Figure 1 describes the nested structure of production.

**FIGURE 1: NESTED PRODUCTION STRUCTURE**



Such nested structures are common in CGE models and it is usually expected that the elasticity of substitution is greater at lower levels of the hierarchy.

At the top level (equations X1 and X2), the sectoral output of each productive activity  $j$  combines value added and total intermediate consumption in fixed shares. In other words, the two aggregate inputs are considered to be strictly complementary, without any possibility of substitution, following a Leontief production function.

$$X1. \quad VA_{j,t} = v_j XST_{j,t}$$

$$X2. \quad CI_{j,t} = io_j XST_{j,t}$$

where

$CI_{j,t}$ : Total intermediate consumption of industry  $j$

$VA_{j,t}$ : Value added of industry  $j$

$XST_{j,t}$ :	Total aggregate output of industry $j$
$io_j$ :	Coefficient (Leontief – intermediate consumption)
$v_j$ :	Coefficient (Leontief – value added)

At the second level, each industry's value added consists of composite labour and capital, following a constant elasticity of substitution (CES) specification. In equation X3, a total factor productivity parameter is introduced. In the construction of a reference scenario, this factor can be set endogenous to allow for the scenario to reach real GDP projections, while labour supply may grow according to demographic estimates. Under simulation, however, the factor is exogenous, and real GDP adjusts to whatever shock is introduced. In addition, to account for the impact climate change might have on productivity, an additional factor  $CCF_{j,t}$  is added.

$$X3. \quad VA_{j,t} = CCF_{j,t} TFP_t B_j^{VA} \left[ \beta_j^{VA} LDC_{j,t}^{-\rho_j^{VA}} + (1 - \beta_j^{VA}) KD_{j,t}^{-\rho_j^{VA}} \right]^{-\frac{1}{\rho_j^{VA}}}$$

With:

$$CC1. \quad CCF_{j,t+1} = CCF_{j,t} \{1 + \delta_{j,t+1}^{CC}\}$$

Where

$CCF_{j,t}$ :	Climate change factor
$KD_{j,t}$ :	Industry $j$ demand for capital
$LDC_{j,t}$ :	Industry $j$ demand for composite labour
$TFP_t$ :	Total factor productivity
$VA_{j,t}$ :	Value added of industry $j$
$B_j^{VA}$ :	Scale parameter (CES – value added)
$\beta_j^{VA}$ :	Share parameter (CES – value added)
$\rho_j^{VA}$ :	Elasticity parameter (CES – value added)
$\delta_{j,t}^{CC}$ :	Change in productivity due to climate change

Profit maximization (or cost minimization) by the firms leads them to employ labour and capital to the point where the value marginal product of each is equal to its price (the wage rate and the rental rate of capital respectively). With a CES production function, such behavior is described by the demand for labour relative to capital of equation X4<sup>3</sup>.

$$X4. \quad LDC_{j,t} = \left[ \frac{\beta_j^{VA} R_{j,t}}{(1 - \beta_j^{VA}) WC_{j,t}} \right]^{\sigma_j^{VA}} KD_{j,t}$$

where

$KD_{j,t}$ :	Industry $j$ demand for capital
$LDC_{j,t}$ :	Industry $j$ demand for composite labour
$R_{j,t}$ :	Rental rate of industry $j$ capital

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<sup>3</sup> See the complete mathematical derivation in DLRM Appendix C1.

$WC_{j,t}$ :	Wage rate of industry $j$ composite labour
$\beta_j^{VA}$ :	Share parameter (CES – value added)
$\sigma_j^{VA}$ :	Elasticity of transformation (CES – value added)

At the bottom level on the value added side, the two categories of labour, indexed as  $l \in L = \{L_{SAL}, L_{SEM}\}$  representing salaried and self-employed workers respectively, are combined following a constant elasticity of substitution (CES) technology (equation X5), which reflects the imperfect substitutability between different types of labour. The firm chooses its labour composition so as to minimize its labour cost given the relative wage rates. Labor demand of each type derives from the first-order conditions of cost minimization by the representative firm, subject to the CES technology<sup>4</sup> (equation X6).

$$X5. \quad LDC_{j,t} = B_j^{LD} \left[ \sum_l \beta_{l,j}^{LD} LD_{l,j,t}^{-\rho_j^{LD}} \right]^{-\frac{1}{\rho_j^{LD}}}$$

$$X6. \quad LD_{l,j,t} = \left[ \frac{\beta_{l,j}^{LD} WC_{j,t}}{W_{l,t}} \right]^{\sigma_j^{LD}} (B_j^{LD})^{\sigma_j^{LD}-1} LDC_{j,t}$$

where

$LD_{l,j,t}$ :	Demand for type $l$ labour by industry $j$
$LDC_{j,t}$ :	Industry $j$ demand for composite labour
$W_{l,t}$ :	Wage rate of type $l$ labour
$WC_{j,t}$ :	Wage rate of industry $j$ composite labour
$B_j^{LD}$ :	Scale parameter (CES – composite labour)
$\beta_{l,j}^{LD}$ :	Share parameter (CES – composite labour)
$\rho_j^{LD}$ :	Elasticity parameter (CES – composite labour)
$\sigma_j^{LD}$ :	Elasticity of substitution (CES – composite labour)

Finally, returning to the second level, but on the intermediate consumption side, it is assumed that intermediate inputs are perfectly complementary (no substitution possibility) and are combined following a Leontief production function. Electricity consumption projections show a sharp increase in the coming years, reflecting the development of industries that are more energy intensive – such as data centers. We introduce an adjustment factor in the intermediate demand function that will be computed endogenously so that the consumption path for electricity matches the projection. Under simulation however, electricity demand is endogenous and the adjustment factor is set exogenous. In addition, a dummy variable is introduced to allow the exclusion of specific sectors.

$$X7. \quad DI_{i,j,t} = DUMMY_j [ADJ_i a_{ij,i,j} CI_{j,t}] + (1 - DUMMY_j) [a_{ij,i,j} CI_{j,t}]$$

where

$CI_{j,t}$ :	Total intermediate consumption of industry $j$
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<sup>4</sup> See the complete mathematical derivation in DLRM Appendix C2.

$DI_{i,j,t}$ :	Intermediate consumption of commodity $i$ by industry $j$
$ADJ_i$ :	Adjustment factor (greater electricity input)
$DUMMY_j$ :	Dummy variable (1 if the electricity intensity adjusts, 0 if not)
$aij_{i,j}$ :	Input-output coefficient

## 2. Producer supplies of products and international trade

Producers' supply behavior is represented by nested CET functions: on the upper level, aggregate output is allocated to individual products; on the lower level, the supply of each product is distributed between the domestic market and exports.

Industries usually produce more than one product. It is assumed that, although an industry can reorganize its production to change the proportions of goods produced, the different products are not perfectly « transformable » into one another. This is represented by means of a constant elasticity of transformation (CET) function that describes how easily the product-mix can be adjusted in response to price changes (equation IX1):

$$IX1. XST_{j,t} = B_j^{XT} \left[ \sum_i \beta_{j,i}^{XT} XS_{j,i,t}^{\rho_j^{XT}} \right]^{\frac{1}{\rho_j^{XT}}}$$

where

$XS_{j,i,t}$ :	Industry $j$ production of commodity $i$
$XST_{j,t}$ :	Total aggregate output of industry $j$
$B_j^{XT}$ :	Scale parameter (CET – total output)
$\beta_{j,i}^{XT}$ :	Share parameter (CET – total output)
$\rho_j^{XT}$ :	Elasticity parameter (CET – total output)

Producers allocate output among products so as to maximize sales revenue, given product prices, subject to equation IX1. Individual product supply functions (equation IX2) are derived from the first-order conditions of revenue maximizing (see DLRM Appendix C5).

$$IX2. XS_{j,i,t} = \frac{XST_{j,t}}{(B_j^{XT})^{1+\sigma_j^{XT}}} \left[ \frac{P_{i,t}}{\beta_{j,i}^{XT} PT_{j,t}} \right]^{\sigma_j^{XT}}$$

where

$P_{i,t}$ :	Basic price of commodity $i$
$PT_{j,t}$ :	Basic price of industry $j$ 's output
$XS_{j,i,t}$ :	Industry $j$ production of commodity $i$
$XST_{j,t}$ :	Total aggregate output of industry $j$
$B_j^{XT}$ :	Scale parameter (CET – total output)
$\beta_{j,i}^{XT}$ :	Share parameter (CET – total output)
$\sigma_j^{XT}$ :	Elasticity of transformation (CET – total output)

Total supply of each commodity is obtained by adding the supply by each commodity, to which withdrawals from inventories are added (equation IX3)

$$IX3. XSI_{i,t} = \sum_j XS_{i,j,t} + VSTK_{i,t}^{OUT}$$

where

$VSTK_{i,t}^{OUT}$ : Inventory change of commodity  $i$  (supply)  
 $XS_{j,i,t}$ : Industry  $j$  production of commodity  $i$   
 $XSI_{i,t}$ : Total supply of commodity  $i$

Total supply of every product is shared out among markets (domestic or export), again with the goal of maximizing the firm's total revenue, given the demand in each market and the various taxes that apply. For all commodities except electricity, it is assumed that production directed to one market is somewhat different from production directed to another market. To account for the particularities of the electricity market, the electricity production has been split between summer production (May to October) and winter production (November to April). The same has been done on the commodity side. Subset  $ele$  represent the electricity market.

$$IX4. XSI_{i,t} = B_i^X \left[ \beta_i^X EX_{i,t}^{\rho_i^X} + (1 - \beta_i^X) DS_{i,t}^{\rho_i^X} \right]^{\frac{1}{\rho_i^X}} \quad \forall i \neq ele$$

where

$DS_{i,t}$ : Supply of commodity  $i$  to the domestic market  
 $EX_{i,t}$ : Quantity of product  $i$  exported  
 $XSI_{i,t}$ : Total supply of commodity  $i$   
 $B_i^X$ : Scale parameter (CET – exports and local sales)  
 $\beta_i^X$ : Share parameter (CET – exports and local sales)  
 $\rho_i^X$ : Elasticity parameter (CET – exports and local sales)

Relative supply functions are derived from the first-order conditions of revenue maximizing subject to the CET function (see DLRM Appendix C6).

$$IX5. EX_{i,t} = \left[ \frac{1 - \beta_i^X}{\beta_i^X} \frac{PE_{i,t}}{PL_{i,t}} \right]^{\sigma_i^X} DS_{i,t} \quad \forall i \neq ele$$

where

$DS_{i,t}$ : Supply of commodity  $i$  to the domestic market  
 $EX_{i,t}$ : Quantity of product  $i$  exported  
 $PE_{i,t}$ : Price received for exported commodity  $i$  (excluding export taxes)  
 $PL_{i,t}$ : Price of local product  $i$  (excluding all taxes on products)  
 $\beta_i^X$ : Share parameter (CET – exports and local sales)  
 $\sigma_i^X$ : Elasticity of transformation (CET – exports and local sales)

For electricity, it is assumed that the domestic price is exogenous. During summer, suppliers provide whatever quantity is domestically demanded at that given price and whatever quantity is left is then

exported. During winter, a fixed share of electricity is exported<sup>5</sup> and the rest is sold on the domestic market. If ever demand during winter exceeds domestic supply, electricity will be imported (IX8).

$$\text{IX6. } XSI_{ele,t} = EX_{ele,t} + DS_{ele,t}$$

$$\text{IX7. } EX_{12-ELE\_WIN',t} = sh_t^{EX} XSI_{12-ELE\_WIN',t}$$

$$\text{IX8. } IM_{12-ELE\_WIN',t} = Q_{12-ELE\_WIN',t} - DD_{12-ELE\_WIN',t}$$

Where

$DS_{ele,t}$ :	Supply of electricity to the domestic market
$EX_{ele,t}$ :	Quantity of electricity exported
$XSI_{ele,t}$ :	Total supply of commodity electricity
$sh_t^{EX}$ :	Share of exports in overall production (winter)

For all other commodities, buyer's behavior is symmetrical to producer behavior, in that it is assumed that local products are imperfect substitutes for imports, or, in other words, that goods are heterogeneous with respect to their origin. So commodities demanded on the domestic market are composite goods, combinations of locally produced goods and imports. The imperfect substitutability between the two is represented by a constant elasticity of substitution (CES) function (equation IX7).

$$\text{IX9. } Q_{i,t} = B_i^M \left[ \beta_i^M IM_{i,t}^{-\rho_i^M} + (1 - \beta_i^M) DD_{i,t}^{-\rho_i^M} \right]^{\frac{-1}{\rho_i^M}} \quad \forall i \neq ele$$

where

$DD_{i,t}$ :	Domestic demand for commodity $i$ produced locally
$IM_{i,t}$ :	Quantity of product $i$ imported
$Q_{i,t}$ :	Quantity demanded of composite commodity $i$
$B_i^M$ :	Scale parameter (CES – composite commodity)
$\beta_i^M$ :	Share parameter (CES – composite commodity)
$\rho_i^M$ :	Elasticity parameter (CES – composite commodity)

Just as sellers seek to maximize revenue, buyers minimize expenses, subject to the CES aggregation function (equation IX7). Relative demand functions derive from the first-order optimum conditions (see DLRM Appendix C7).

$$\text{IX10. } IM_{i,t} = \left[ \frac{\beta_i^M}{1 - \beta_i^M} \frac{PD_{i,t}}{PM_{i,t}} \right]^{\sigma_i^M} DD_{i,t} \quad \forall i \neq ele$$

where

$DD_{i,t}$ :	Domestic demand for commodity $i$ produced locally
$IM_{i,t}$ :	Quantity of product $i$ imported

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<sup>5</sup> Some facilities are directly connected to India's grid and thus, even if additional electricity is needed in Bhutan, there would still be some exports. The share is calibrated in the model so as to represents the evolution of that share through time.

$PD_{i,t}$ :	Price of local product $i$ sold on the domestic market (including all taxes and margins)
$PM_{i,t}$ :	Price of imported product $i$ (including all taxes and margins)
$\beta_i^M$ :	Share parameter (CES – composite commodity)
$\sigma_i^M$ :	Elasticity of substitution (CES – composite commodity)

### 3. Demand

The demand for goods and services, whether domestically produced or imported, consists of intermediate demand, household consumption demand, demand for investment purposes, demand by public administrations, and demand as transport or trade margins.

Households follows Stone-Geary utility functions, from which derives the Linear Expenditure System (LES). A characteristic of these utility functions is that there is a minimum level of consumption of each commodity. Compared to the Cobb-Douglas utility function, the LES imposes neither zero cross-price elasticities between all pairs of goods, nor unit income-elasticities for all goods. Thus, it offers a degree of flexibility with respect to substitution possibilities in response to relative price changes. Type  $h$  household demand for each good (equation D1) is determined by utility maximization subject to the budget constraint (see DLRM Appendix C4).

$$D1. PC_{i,t}C_{i,h,t} = PC_{i,t}C_{i,h,t}^{MIN} + \gamma_{i,h}^{LES}(CTH_{h,t} - \sum_{ij} PC_{ij,t}C_{ij,h,t}^{MIN})$$

where

$C_{i,h,t}$ :	Consumption of commodity $i$ by type $h$ households
$C_{i,h,t}^{MIN}$ :	Minimum consumption of commodity $i$ by type $h$ households
$CTH_{h,t}$ :	Consumption budget of type $h$ households
$PC_{i,t}$ :	Purchaser price of composite commodity $i$ (including all taxes and margins)
$\gamma_{i,h}^{LES}$ :	Marginal share of commodity $i$ in type $h$ household consumption budget

Demand for investment purposes includes both gross fixed capital formation ( $GFCF$ ) and changes in inventories. Since changes in inventories in the SAM may be positive or negative, we have distinguished the changes that are negative ( $VSTK\_OUT$ ) as withdrawals contribute to total supply from positive changes ( $VSTK\_IN$ ) which are part of total demand. In both cases, changes in inventories are not really compatible with a model in which it is assumed that all markets are in equilibrium and the reasons why these changes happen may be quite diverse. For this reason, all changes in inventories are set exogenous.

$GFCF$  expenditure is obtained by subtracting the net cost of changes in inventories from total investment expenditure (equation D2). This expenditure is then distributed among commodities in fixed shares (equation D3). The same hypothesis is made regarding government current expenditures on goods and services (equation D4). With a given current expenditure budget, the quantity demanded of each commodity varies inversely with its price.

$$D2. GFCF_t = IT_t - \sum_i PC_{i,t}VSTK_{i,t}^{IN} + \sum_i P_{i,t}VSTK_{i,t}^{OUT}$$

$$D3. PC_{i,t}INV_{i,t} = \gamma_i^{INV} GFCF_t$$

$$D4. PC_{i,t}CG_{i,t} = \gamma_i^{GVT} G_t$$

where

$CG_{i,t}$ :	Public consumption of commodity $i$ (volume)
$GFCF_t$ :	Gross fixed capital formation
$G_t$ :	Current government expenditures on goods and services
$INV_{i,t}$ :	Final demand of commodity $i$ for investment purposes
$IT_t$ :	Total investment expenditures
$P_{i,t}$ :	Basic price of commodity $i$
$PC_{i,t}$ :	Purchaser price of composite commodity $i$ (including all taxes and margins)
$VSTK_{i,t}^{IN}$ :	Inventory change of commodity $i$ (demand)
$VSTK_{i,t}^{OUT}$ :	Inventory change of commodity $i$ (supply)
$\gamma_i^{GVT}$ :	Share of commodity $i$ in total current public expenditures on goods and services
$\gamma_i^{INV}$ :	Share of commodity $i$ in total investment expenditures

Goods and services may also be used as inputs in the production process. Intermediate demand for each commodity is simply the sum of industry demands.

$$D5. DIT_{i,t} = \sum_j DI_{i,j,t}$$

where

$DI_{i,j,t}$ :	Intermediate consumption of commodity $i$ by industry $j$
$DIT_{i,t}$ :	Total intermediate demand for commodity $i$

Additionally, some services, such as transport and retail and wholesale trade, are used to move commodities and make them available to the market. Margin rates are applied to the volume of domestic production and imports to determine the quantities of these margin services required to distribute commodities to buyers.

$$D6. MRGN_{i,t} = \sum_{ij} tmrg_{i,ij} DD_{ij,t} + \sum_{ij} tmrg_{i,ij} IM_{ij,t}$$

where

$DD_{i,t}$ :	Domestic demand for commodity $i$ produced locally
$IM_{i,t}$ :	Quantity of product $i$ imported
$MRGN_{i,t}$ :	Demand for commodity $i$ as a trade or transport margin
$tmrg_{ij,i}$ :	Rate of margin $ij$ applied to commodity $i$

Finally, tourists visiting Bhutan also purchase goods and services. Here, it is assumed that the budget share for each commodity is constant.

$$D7. PC_{i,t}CT_i = \gamma_i^{TOUR} CTT_t$$

Where

$CT_{i,t}$ :	Tourists purchases of commodity $i$
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$CTT_t$ :	Tourists budget net of sustainable development fee
$PC_{i,t}$ :	Purchaser price of composite commodity $i$ (including all taxes and margins)
$\gamma_i^{TOUR}$ :	Share of commodity $i$ in total tourists expenditures

## 4. Income and savings

In the SAM for Bhutan, households are disaggregated between urban and rural households, respectively indexed as  $h, hj \in H \subset AG = \{H_{HURB}, H_{HRUR}\}$ . Elements of the set  $AG$  of all agents are designated as  $ag, agj \in AG = H \cup \{FIRM, TOUR, GVT, ROW\} = \{H_{HURB}, H_{HRUR}, FIRM, TOUR, GVT, ROW\}$ .

### 4.1 Households

Consistent with the Bhutanese SAM, household income comes from two sources: labour income and transfers received from other agents.

$$H1. YH_{h,t} = YHL_{h,t} + YHTR_{h,t}$$

where

$YH_{h,t}$ :	Total income of type $h$ households
$YHL_{h,t}$ :	Labor income of type $h$ households
$YHTR_{h,t}$ :	Transfer income of type $h$ households

Each household type receives earnings from each type of labour according to their supply of labour on each market. For their activities in Bhutan, the workers receive the wage rate determined by the market, whereas they received a fixed exogenous wage rate if they work outside of Bhutan (equation H2).

$$H2. YHL_{h,t} = \sum_l (W_{l,t} \sum_l LS_{h,l,t}^B (1 - unr_{h,l,t})) + e_t \sum_l W_{l,t}^W LS_{h,l,t}^W$$

$e_t$ :	Exchange rate (numeraire)
$LS_{h,l,t}^B$ :	Supply of type $l$ labour by type $h$ household in Bhutan
$LS_{h,l,t}^W$ :	Supply of type $l$ labour by type $h$ household outside Bhutan
$unr_{h,l,t}$ :	Unemployment rate for type $l$ labour in region $h$
$W_{l,t}$ :	Wage rate of type $l$ labour
$W_{l,t}^W$ :	Wage rate of type $l$ labour received outside Bhutan
$YHL_{h,t}$ :	Labor income of type $h$ households

In each region (rural or urban) households are endowed with an exogenous amount of labour they can supply on the market ( $LS_{h,l}$ ). They can either work in Bhutan ( $LS_{h,l}^B$ ) or outside the country ( $LS_{h,l}^W$ ). It is assumed that the switch between the two destinations is not perfect and a CET function is used here to represent any frictions workers can face (equation H3). They base their decision on the wage rate they can get on each market, maximizing total labour income subject to the CET aggregator. The wage rate a worker can obtain for his work outside Bhutan is exogenous, while the one they get in Bhutan is determined by the market condition. Note that workers account for unemployment in their computation of what they would get while working in Bhutan.

$$H3. LS_{h,l,t} = B_{h,l}^{LS} \left[ \beta_{h,l}^{LS} LS_{h,l,t}^{\rho_{h,l}^{LS}} + (1 - \beta_{h,l}^{LS}) LS_{h,l,t}^W \right]^{\frac{1}{\rho_{h,l}^{LS}}}$$

$$H4. LS_{h,l,t}^B = \left[ \frac{1 - \beta_{h,l}^{LS} W_l(1 - unr_{h,l,t})}{\beta_{h,l}^{LS} e_t W_{l,t}^W} \right]^{\sigma_{h,l}^{LS}} LS_{h,l,t}^W$$

Where

$e_t$ :	Exchange rate (numeraire)
$LS_{l,h,t}$ :	Supply of type $l$ labour in region $h$
$LS_{h,l,t}^B$ :	Supply of type $l$ labour by type $h$ household in Bhutan
$LS_{h,l,t}^W$ :	Supply of type $l$ labour by type $h$ household outside Bhutan
$unr_{h,l,t}$ :	Unemployment rate for type $l$ labour in region $h$
$W_{l,t}$ :	Wage rate of type $l$ labour
$W_{l,t}^W$ :	Wage rate of type $l$ labour received outside Bhutan
$B_{h,l}^{LS}$ :	Scale parameter (CET – labour supply)
$\beta_{h,l}^{LS}$ :	Share parameter (CET – labour supply)
$\rho_{h,l}^{LS}$ :	Elasticity parameter (CET – labour supply)
$\sigma_{h,l}^{LS}$ :	Elasticity of transformation (CET – labour supply)

A “wage-curve” type of formulation is used to explain unemployment. This type of modeling is common in CGE models although it relies more on empirical evidences than on microeconomic theory<sup>6</sup>. Equation H5 basically says that the greater the real wage rate is, the lower the unemployment would be, since the value of the elasticity is negative. Also note that in all equations related to the labour market, parameters are indexed in both  $L$  and  $H$  allowing for different behaviour depending on the region and the type of labour.

$$H5. A_{h,l}^{UN} unr_{h,l,t} = \left[ \frac{W_{l,t}}{PIXCON_t} \right]^{\frac{1}{\sigma_{h,l}^{UN}}}$$

Where

$PIXCON_t$ :	Consumer price index
$unr_{h,l,t}$ :	Unemployment rate for type $l$ labour in region $h$
$W_{l,t}$ :	Wage rate of type $l$ labour
$A_{h,l}^{UN}$ :	Scale parameter (wage curve)
$\sigma_{h,l}^{UN}$ :	Elasticity (wage curve)

Transfer income is simply the sum of all transfers received by type  $h$  households (equation H6).

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<sup>6</sup> See Blanchflower and Oswald (1995)

$$H6. YHTR_{h,t} = \sum_{ag} TR_{h,ag,t}$$

Where

$TR_{h,ag}$ : Transfers from agent  $ag$  to type  $h$  households

$YHTR_h$ : Transfer income of type  $h$  households

Household disposable income is obtained by subtracting direct taxes and household transfers to government (equation H4) and whatever disposable income is left after savings and transfers to other agents is entirely dedicated to consumption (equation H5). Finally, household savings are a linear function of disposable income.

$$H7. YDH_{h,t} = YH_{h,t} - TDH_{h,t} - TR_{gvt,h,t}$$

$$H8. CTH_{h,t} = YDH_{h,t} - SH_{h,t} - \sum_{agn} TR_{agn,h,t}$$

$$H9. SH_{h,t} = PIXCON_t sh0_{h,t} + sh1_{h,t} YDH_{h,t}$$

where

$CTH_{h,t}$ : Consumption budget of type  $h$  households

$PIXCON_t$ : Consumer price index

$SH_{h,t}$ : Savings of type  $h$  households

$TDH_{h,t}$ : Income taxes of type  $h$  households

$TR_{gvt,h,t}$ : Transfers from type  $h$  households to government

$TR_{agn,h,t}$ : Transfers from type  $h$  households to non-government agents

$YDH_{h,t}$ : Disposable income of type  $h$  households

$YH_{h,t}$ : Total income of type  $h$  households

$sh0_{h,t}$ : Intercept (type  $h$  household savings)

$sh1_{h,t}$ : Slope (type  $h$  household savings)

## 4.2 Tourists

In order to take into account the tourists spending in Bhutan, an additional agent is created. The total budget tourists spend in Bhutan ( $YT$ ) is totally funded by an exogenous transfer from abroad and whatever is left after paying the sustainable development fee ( $SDF$ ) constitutes the budget tourists spend in goods and services in Bhutan ( $CTT$ ).

$$TO1. YT_t = TR_{tour,row,t}$$

$$TO2. CTT_t = YT_t - SDF_t$$

where

$CTT_t$ : Tourists budget net of sustainable development fee

$SDF_t$ : Sustainable development fee

$TR_{tour,row,t}$ : Transfers from agent row to agent tour

$YT_t$ : Total tourists budget

## 4.3 Businesses

The business account in the SAM is a hybrid account that combines all firms' income and expenditures with property income. In the model, businesses income consists of operating surplus net of royalties and

of consumption of fixed capital, and of transfers received from other agents, including interest payments. Note that royalties paid by the government, variable  $ROY_j$ , depends on the industry.

$$\begin{aligned} \text{F1. } YF_t &= YFK_t + YFTR_t \\ \text{F2. } YFK_t &= \left( \sum_j R_{j,t} KD_{j,t} - ROY_{j,t} \right) - DEP_t \\ \text{F3. } YFTR_t &= \sum_{ag} TR_{FIRM,ag,t} \end{aligned}$$

where

$DEP_t$ :	Consumption of fixed capital
$KD_{j,t}$ :	Industry $j$ demand for capital
$R_{j,t}$ :	Rental rate of industry $j$ capital
$ROY_{j,t}$ :	Royalties paid by industry $j$
$TR_{FIRM,ag,t}$ :	Transfers from agent $ag$ to firms
$YF_t$ :	Total income of businesses
$YFK_t$ :	Capital income of businesses
$YFTR_t$ :	Transfer income of businesses

Disposable income is computed by deducting business income taxes from total income (equation F4) and business savings are the residual that remains after subtracting transfers to other agents from disposable income (equation F5).

$$\begin{aligned} \text{F4. } YDF_t &= YF_t - TDF_t \\ \text{F5. } SF_t &= YDF_t - \sum_{ag} TR_{ag,FIRM,t} \end{aligned}$$

where

$SF_t$ :	Savings of businesses
$TDF_t$ :	Income taxes of businesses
$TR_{ag,FIRM,t}$ :	Transfers from firms to agent $ag$
$YDF_t$ :	Disposable income of businesses
$YF_t$ :	Total income of businesses

## 4.4 Government

The government draws its income taxes on products, taxes on production, income taxes, royalties and transfers (equation G1). Taxes on products consist of indirect taxes on domestic consumption, taxes and duties on imports, and taxes on exports (equation G2).

$$\begin{aligned} \text{G1. } YG_t &= TPRCTS_t + TIPT_t + TDHT_t + TDF_t + YGR_t + YGTR_t \\ \text{G2. } TPRCTS_t &= TICT_t + TIMT_t + TIXT_t \end{aligned}$$

where

$TDHT_t$ :	Total government revenue from household income taxes
$TICT_t$ :	Total government receipts of indirect taxes on commodities
$TIMT_t$ :	Total government revenue from import duties
$TIXT_t$ :	Total government revenue from export taxes
$TIPT_t$ :	Total government revenue from production taxes
$TPRCTS_t$ :	Total government revenue from taxes on products and imports

$YG_t$ : Total government income  
 $YGR_t$ : Government capital income (royalties)  
 $YGTR_t$ : Government transfer income

The government can implement two types of taxes on products. Equation G3 to G6 describes how these taxes are levied. Note that domestic taxes apply on the sales value including margins and custom duties whenever the latter exist. Other taxes collected are taxes and duties on imported products, taxes on exports and taxes on production.

$$G3. TICT_t = \sum_i TIC_{i,t}$$

$$G4. TIC_{i,t} = ttic_{i,t} \left\{ (PL_{i,t} + \sum_{ij} PC_{ij,t} tmr g_{ij,i}) DD_{i,t} + ((1 + ttim_{i,t}) PWM_{i,t} e_t + \sum_{ij} PC_{ij,t} tmr g_{ij,i}) IM_{i,t} \right\}$$

$$G5. TIMT_t = \sum_i TIM_{i,t}$$

$$G6. TIM_{i,t} = ttim_{i,t} PWM_{i,t} e_t IM_{i,t}$$

$$G7. ttim_{i,t} = cduty_{i,t} + stax_{i,t} + gtax_{i,t}$$

$$G8. TIXT_t = \sum_i TIX_{i,t}$$

$$G9. TIX_{i,t} = ttix_{i,t} PE_{i,t} EX_{i,t}$$

$$G10. TIPT_t = \sum_j TIP_{j,t}$$

$$G11. TIP_{j,t} = ttip_{j,t} PP_{j,t} XST_{j,t}$$

Where

$DD_{i,t}$ : Domestic demand for commodity  $i$  produced locally  
 $e_t$ : Exchange rate (numeraire)  
 $IM_{i,t}$ : Quantity of product  $i$  imported  
 $PC_{i,t}$ : Purchaser price of composite commodity  $i$  (including all taxes and margins)  
 $PL_{i,t}$ : Price of local product  $i$  (excluding all taxes on products)  
 $PP_{j,t}$ : Industry  $j$  unit cost excluding taxes on production  
 $PWM_{i,t}$ : World price of imported product  $i$  (expressed in foreign currency)  
 $TIC_{i,t}$ : Government revenue from indirect taxes on product  $i$   
 $TICT_t$ : Total government receipts of indirect taxes on commodities  
 $TIM_{i,t}$ : Government revenue from import duties on product  $i$   
 $TIMT_t$ : Total government revenue from import duties  
 $TIP_{j,t}$ : Government revenue from taxes on industry  $j$  production  
 $TIPT_t$ : Total government revenue from production taxes  
 $TIX_{i,t}$ : Government revenue from export taxes on product  $i$   
 $TIXT_t$ : Total government revenue from export taxes  
 $cduty_{i,t}$ : Rate of custom duties on imports of commodity  $i$   
 $gtax_{i,t}$ : Rate of green taxes on imports of commodity  $i$   
 $stax_{i,t}$ : Rate of sales taxes on imports of commodity  $i$   
 $ttic_{i,t}$ : Tax rate on commodity  $i$   
 $ttim_{i,t}$ : Overall of tax rate on imports of commodity  $i$   
 $ttip_{j,t}$ : Tax rate on the production of industry  $j$   
 $ttix_{i,t}$ : Rate of taxes on exports of commodity  $i$   
 $tmrg_{ij,i}$ : Rate of margin  $ij$  applied to commodity  $i$

Similarly to what has been done with household savings, personal income taxes are described as a linear function of income from salaries (equation G10) and business income taxes are levied on firms' capital (G11). When a non-zero intercept is applied, the marginal rate of taxation is different from the average rate.

$$G12. \quad TDHT_t = \sum_h TDH_{h,t}$$

$$G13. \quad TDH_{h,t} = PIXCON_t ttdh0_{h,t} + ttdh1_{h,t} W_{SAL',t} LS_{h,SAL',t}^B (1 - unr_{h,SAL',t})$$

$$G14. \quad TDF_t = PIXCON_t ttdf0_t + ttdf1_t YFK_t$$

where

$LS_{h,l,t}^B$ : Supply of type  $l$  labour by type  $h$  household in Bhutan

$PIXCON_t$ : Consumer price index

$TDH_{h,t}$ : Income taxes of type  $h$  households

$TDHT_t$ : Total government revenue from household income taxes

$unr_{h,l,t}$ : Unemployment rate for type  $l$  labour in region  $h$

$YFK_t$ : Capital income of businesses

$ttdf0_t$ : Intercept (income taxes of businesses)

$ttdf1_t$ : Marginal income tax rate of businesses

$ttdh0_{h,t}$ : Intercept (income taxes of type  $h$  households)

$ttdh1_{h,t}$ : Marginal income tax rate of type  $h$  households

The government receives royalties from industries that use natural resources in their production process (forestry, mining and hydroelectric production, equation G12). Additionally, tourists visiting Bhutan pay a sustainable development fee ( $SDF$ ). Finally, government also receives transfers from other agents (equation G14).

$$G15. \quad ROY_{j,t} = \lambda_j^{RKG} R_{j,t} KD_{j,t}$$

$$G16. \quad YGR_t = \sum_j R_{j,t} ROY_{j,t} + SDF_t$$

$$G17. \quad YGTR_t = \sum_{agn} TR_{gvt,agn,t}$$

where

$KD_{j,t}$ : Industry  $j$  demand for capital

$R_{j,t}$ : Rental rate of industry  $j$  capital

$ROY_{j,t}$ : Royalties paid by industry  $j$

$SDF_t$ : Sustainable Development Fee

$TR_{gvt,agn,t}$ : Transfers from agent  $agn$  to government

$YGTR_t$ : Government transfer income

$\lambda_j^{RKG}$ : Share of capital income (royalties) received by government

The current government budget surplus or deficit (positive or negative savings) is the difference between its revenue and its expenditures. The latter consist of transfers to agents and current expenditures on goods and services. In the current closure of the government account, the total budget for current expenditures on goods and services ( $G$ ) is fixed and any variation in the government income will translate into a change in its surplus/deficit.

$$G18. \quad SG_t = YG_t - \sum_{agn} TR_{agn,gvt,t} - G_t$$

where

$G_t$ : Current government expenditures on goods and services

$SG_t$ : Government savings

$TR_{agng,gvt,t}$ : Transfers from government to agent  $agng$

$YG_t$ : Total government income

## 4.5 Rest of the world

The rest of the world receives payments for the value of imports, part of the income of labour (foreigners working in Bhutan), and transfers from domestic agents (equation W1). Foreign spending in the domestic economy consists of the value of exports, transfers to domestic agents and payment to Bhutanese working abroad. The difference between foreign receipts and spending is the amount of rest-of-the-world savings (equation W2), which are equal in absolute value to the current account balance, but of opposite sign (equation W3). In the current closure, the current account balance is exogenous and the nominal exchange rate is the numeraire.

$$W1. YROW_t = e_t \sum_i PWM_{i,t} IM_{i,t} + \sum_{agd} TR_{row,agd,t} + \sum_l W_{l,t} LS_{l,t}^{ROW}$$

$$W2. SROW_t = YROW_t - e_t \sum_i PWX_{i,t} EX_{i,t} - \sum_{agd} TR_{agd,row,t} - e_t \sum_{h,l} W_{l,t}^W LS_{h,l,t}^W$$

$$W3. SROW_t = -CAB_t$$

where

$CAB_t$ : Current account balance

$e_t$ : Exchange rate (numeraire)

$EX_{i,t}$ : Quantity of product  $i$  exported

$IM_{i,t}$ : Quantity of product  $i$  imported

$LS_{l,t}^{ROW}$ : Non-resident labour supply

$LS_{h,l,t}^W$ : Supply of type  $l$  labour by type  $h$  household outside Bhutan

$PWM_{i,t}$ : World price of imported product  $i$  (expressed in foreign currency)

$PWX_{i,t}$ : World price of exported product  $i$  (expressed in foreign currency)

$SROW_t$ : Rest-of-the-world savings

$TR_{agd,row,t}$ : Transfers from the rest of the world to agent  $agd$

$TR_{row,agd,t}$ : Transfers from agent  $agd$  to the rest of the world

$W_{l,t}$ : Wage rate of type  $l$  labour

$W_{l,t}^W$ : Wage rate of type  $l$  labour received outside Bhutan

$YROW_t$ : Rest-of-the-world income

## 4.6 Transfers

Household transfers to non-government agents and business transfers are simply proportional to disposable income. Household transfers to government are treated in the same way as household income taxes. All other transfers are initially set equal to their SAM values (variables with sup-script O) and indexed to the consumer price index and to the real GDP growth index. Transfers from the government to the rest of the world are disaggregated to show the interests paid on loans granted for the construction of hydropower infrastructures (**Error! Reference source not found.**).

$$\begin{aligned}
\text{T1. } TR_{agn,g,h,t} &= \lambda_{agn,g,h}^{TR} YDH_{h,t} \\
\text{T2. } TR_{gvt,h,t} &= PIXCON_t tr0_{h,t} + tr1_{h,t} YH_{h,t} \\
\text{T3. } TR_{ag,FIRM,t} &= \lambda_{ag,FIRM}^{TR} YDF_t \\
\text{T4. } TR_{agd,gvt,t} &= PIXCON_t TR_{agd,gvt,t}^0 X_t^{GDP} \\
\text{T5. } TR_{row,gvt,t} &= PIXCON_t TR_{row,gvt,t}^0 X_t^{GDP} + INT_t^{ELE} \\
\text{T6. } TR_{agd,row,t} &= PIXCON_t TR_{agd,row,t}^0 X_t^{GDP} \\
\text{T7. } TR_{ag,tour,t} &= PIXCON_t TR_{ag,tour,t}^0 X_t^{GDP}
\end{aligned}$$

where

$PIXCON_t$ :	Consumer price index
$TR_{ag,agj,t}$ :	Transfers from agent $agj$ to agent $ag$
$YDF_t$ :	Disposable income of businesses
$YDH_{h,t}$ :	Disposable income of type $h$ households
$YH_{h,t}$ :	Total income of type $h$ households
$\lambda_{ag,agj}^{TR}$ :	Share parameter (transfer functions)
$tr0_{gvt,h,t}$ :	Intercept (transfers by type $h$ households to government)
$tr1_{gvt,h,t}$ :	Marginal rate of transfers by type $h$ households to government
$X_t^{GDP}$ :	Real GDP index (2017=1)

## 5. Prices

### 5.1 Production

The different prices and price indexes naturally depend on the hypotheses and functional forms already stated. In aggregations, the price of an aggregate is a weighted sum of the prices of its components. The weights are determined by equating the value of the aggregate to the sum of the values of its components, given the quantity of the aggregate (which is determined from the aggregator function). The weight assigned the price of each component is therefore the ratio of its volume (or quantity) to the volume (or quantity) of the aggregate. Only in Leontief fixed-proportions aggregations are the weights invariant to relative price changes; in other cases, component proportions, and, consequently, component price weights, change in response to relative price changes, and they change more or less sharply, depending on the elasticity of substitution or transformation. For instance, the unit cost of an industry's output (including taxes directly related to the use of capital and labour, but excluding other taxes on production) is a weighted sum of the prices of value added and aggregate intermediate consumption (equation P1).

$$\text{P1. } PP_{j,t} = \frac{PVA_{j,t}VA_{j,t} + PCI_{j,t}CI_{j,t}}{XST_{j,t}}$$

Here, the weights are  $VA_j/XST_j$  and  $CI_j/XST_j$ . Multiplying both sides of equation P1 by  $XST_j$  yields the value accounting identity  $PP_j XST_j = PVA_j VA_j + PCI_j CI_j$ . The same principle applies to the prices of other aggregates. The price of aggregate intermediate consumption is a combination of the commodity prices of the industry's intermediate inputs (equation P3), just as the price of value added is a combination of the prices of composite labour and capital (equation P4).

Since various forms of taxation appear in the model, it is necessary to define the relationship between prices before taxes, and prices including taxes. The basic price of production is obtained from the unit cost by adding taxes on production (equation P2).

$$P2. PT_{j,t} = (1 + ttip_{j,t})PP_{j,t}$$

$$P3. PCI_{j,t} = \frac{\sum_i PC_{i,t} DI_{i,j,t}}{CI_{j,t}}$$

$$P4. PVA_{j,t} = \frac{WC_{j,t}LDC_{j,t} + R_{j,t}KD_{j,t}}{VA_{j,t}}$$

where

$CI_{j,t}$ :	Total intermediate consumption of industry $j$
$DI_{i,j,t}$ :	Intermediate consumption of commodity $i$ by industry $j$
$KD_{j,t}$ :	Industry $j$ demand for capital
$LDC_{j,t}$ :	Industry $j$ demand for composite labour
$PC_{i,t}$ :	Purchaser price of composite commodity $i$ (including all taxes and margins)
$PCI_{j,t}$ :	Intermediate consumption price index of industry $j$
$PP_{j,t}$ :	Industry $j$ unit cost excluding taxes on production
$PT_{j,t}$ :	Basic price of industry $j$ 's output
$PVA_{j,t}$ :	Price of industry $j$ value added
$R_{j,t}$ :	Rental rate of industry $j$ capital
$VA_{j,t}$ :	Value added of industry $j$
$WC_{j,t}$ :	Wage rate of industry $j$ composite labour
$XST_{j,t}$ :	Total aggregate output of industry $j$
$ttip_{j,t}$ :	Tax rate on the production of industry $j$

## 5.2 International trade

Exporting industries have the possibility of selling their output on the international market or the domestic market. So the price of their aggregate production is a weighted sum of the price obtained on each market, following the price aggregation principle. The weight assigned to each market is proportional to the quantity sold on that market (equation P5); these weights vary in response to relative price changes, more or less sharply, depending on the elasticity of transformation in the CET.

$$P5. P_{i,t} = \frac{PE_{i,t}EX_{i,t} + PL_{i,t}DS_{i,t}}{XSI_{i,t}}$$

The price paid by purchasers on the export market corresponds to the one received by the producer, to which we add export taxes (equation P6).

$$P6. e_t P W X_{i,t} = P E_{i,t} (1 - t t i x_{i,t})$$

As was previously explained, commodities purchased on the domestic market are composites. The price of the composite is a weighted sum of the price paid for domestically produced and imported goods (equation P9). The price paid for the local product is the sum of the price received by the producer, margins, and indirect taxes (equation P7). Similarly, the price paid for the imported product is the world price, translated into the local currency, plus taxes and duties on imports, margins, and domestic indirect taxes (equation P8).

$$P7. P D_{i,t} = (1 + t t i c_{i,t}) (P L_{i,t} + \sum_{ij} P C_{i,t} t m r g_{ij,i})$$

$$P8. P M_{i,t} = (1 + t t i c_{i,t}) \left( (1 + t t i m_{i,t}) e_t P W M_{i,t} + \sum_{ij} P C_{ij,t} t m r g_{ij,i} \right)$$

$$P9. P C_{i,t} = \frac{P M_{i,t} I M_{i,t} + P D_{i,t} D D_{i,t}}{Q_{i,t}}$$

where

$DD_{i,t}$ :	Domestic demand for commodity $i$ produced locally
$DS_{i,t}$ :	Supply of commodity $i$ to the domestic market
$e_t$ :	Exchange rate (numeraire)
$EX_{i,t}$ :	Quantity of product $i$ exported
$P_{i,t}$ :	Basic price of commodity $i$
$PC_{i,t}$ :	Purchaser price of composite commodity $i$ (including all taxes and margins)
$PD_{i,t}$ :	Price of local product $i$ sold on the domestic market (including all taxes and margins)
$PL_{i,t}$ :	Price of local product $i$ (excluding all taxes on products)
$PM_{i,t}$ :	Price of imported product $i$ (including all taxes and margins)
$PE_{i,t}$ :	Price received for exported commodity $i$ (excluding export taxes)
$PWM_{i,t}$ :	World price of imported product $i$ (expressed in foreign currency)
$Q_{i,t}$ :	Quantity demanded of composite commodity $i$
$XSI_{i,t}$ :	Total supply of commodity $i$
$t m r g_{ij,i}$ :	Rate of margin $ij$ applied to commodity $i$
$t t i c_{i,t}$ :	Tax rate on commodity $i$
$t t i m_{i,t}$ :	Rate of taxes and duties on imports of commodity $i$
$t t i x_{i,t}$ :	Export tax rate on exported commodity $i$

### 5.3 Price indexes

Finally, four price indexes have been defined: the GDP deflator (equation P10), the consumer price index (equation P11), the investment price index (equation P12), and the public expenditures price index (equation P13). The first is a Fisher index (see DLRM Appendix C8), the second is a Laspeyres index, and the third and fourth are exact price indexes, dual to the Cobb-Douglas functions which describe commodity demand for investment purposes and for public consumption (see DLRM Appendix C9).

$$P10.PIXGDP_t = \sqrt{\frac{\sum_j \left( \frac{PVA_{j,t} + TIP_{j,t}}{VA_{j,t}} \right) VA_j^O \sum_j (PVA_{j,t} VA_{j,t} + TIP_{j,t})}{\sum_j (PVA_j^O VA_j^O + TIP_j^O) \sum_j \left( PVA_j^O + \frac{TIP_j^O}{VA_j^O} \right) VA_{j,t}}}$$

$$P11.PIXCON_t = \frac{\sum_i PC_{i,t} \sum_h C_{i,h}^0}{\sum_{ij} PC_{ij}^0 \sum_h C_{ij,h}^0}$$

$$P12.PIXINV_t = \prod_i \left( \frac{PC_{i,t}}{PC_i^0} \right)^{\gamma_i^{INV}}$$

$$P13.PIXGVT_t = \prod_i \left( \frac{PC_{i,t}}{PC_i^0} \right)^{\gamma_i^{GVT}}$$

where

$C_{i,h,t}$ :	Consumption of commodity $i$ by type $h$ households
$PC_{i,t}$ :	Purchaser price of composite commodity $i$ (including all taxes and margins)
$PIXCON_t$ :	Consumer price index
$PIXGDP_t$ :	GDP deflator
$PIXGVT_t$ :	Public expenditures price index
$PIXINV_t$ :	Investment price index
$PVA_{j,t}$ :	Price of industry $j$ value added
$TIP_{j,t}$ :	Government revenue from taxes on industry $j$ production
$VA_{j,t}$ :	Value added of industry $j$
$\gamma_i^{GVT}$ :	Share of commodity $i$ in total current public expenditures on goods and services
$\gamma_i^{INV}$ :	Share of commodity $i$ in total investment expenditures

## 6. Equilibrium

Supply and demand equilibrium must be verified for the goods and services market, and for the factors of production market. Thus, equation EQ1 defines the equilibrium between the supply and demand of each commodity on the domestic market.

$$\text{EQ1. } Q_{i,t} = \sum_h C_{i,h,t} + CG_{i,t} + CT_{i,t} + INV_{i,t} + VSTK_{i,t}^{IN} + DIT_{i,t} + MRGN_{i,t}$$

where

$C_{i,h,t}$ :	Consumption of commodity $i$ by type $h$ households
$CG_{i,t}$ :	Public consumption of commodity $i$ (volume)
$CT_{i,t}$ :	Tourists purchases of commodity $i$
$DIT_{i,t}$ :	Total intermediate demand for commodity $i$
$MRGN_{i,t}$ :	Demand for commodity $i$ as a trade or transport margin
$Q_{i,t}$ :	Quantity demanded of composite commodity $i$
$VSTK_{i,t}^{IN}$ :	Inventory change of commodity $i$ (demand)

Equations EQ2 ensure the equilibrium between total demand for type of workers and available supply, inclusive of foreigners working in Bhutan. It is assumed that while there might be unemployment for Bhutanese workers, all foreigners coming to Bhutan find a job. Keep in mind that it is through this equation that the wage rate is determined for each type of workers.

$$\text{EQ2. } \sum_j LD_{l,j,t} = \sum_h LS_{h,l,t}^B (1 - unnr_{h,l,t}) + LS_{l,t}^{ROW}$$

where

$LD_{l,j,t}$ :	Demand for type $l$ labour by industry $j$
$LS_{h,l,t}^B$ :	Supply of type $l$ labour by type $h$ household in Bhutan
$LS_{l,t}^{ROW}$ :	Non-resident labour supply
$unnr_{h,l,t}$ :	Unemployment rate for type $l$ labour in region $h$

For capital, as the stock of capital is sector specific, equation EQ3 basically computes the total stock of capital in the economy, the rental rate of capital being sector specific. As the capital used in the electricity sectors  $KDE_t$  is the same during summer and winter, it is presented separately and not included in the sum to avoid double counting.

$$\text{EQ3. } \sum_{j \neq ele} KD_{j,t} + KDE_t = KS_t$$

where

$KD_{j,t}$ :	Industry $j$ demand for capital
$KDE_t$ :	Demand for capital by the electricity sectors
$KS_t$ :	Supply of capital

Likewise, total investment expenditure must be equal to the sum of agents' savings plus consumption of fixed capital (equation EQ4). Gross overall surplus differs from net overall surplus by the consumption of fixed capital (variable DEP), which is allocated to savings. Equation EQ5 states that the value of the

consumption of fixed capital is a proportion of total capital stock, multiplied by the investment price. In other words, DEP reflects the cost of replacing the depreciated stock of capital, accounting for impacts climate change might have on depreciation.

$$\text{EQ4. } IT_t = \sum_h SH_{h,t} + SF_t + SG_t + SROW_t + DEP_t$$

$$\text{EQ5. } DEP_t = \sum_{j \neq ele} (\delta_j + \delta_{j,t}^{CC}) KD_{j,t} PK_t + (\delta^E + \delta_{ele,t}^{CC}) KDE_t PK_t$$

where

$DEP_t$ :	Consumption of fixed capital
$KD_{j,t}$ :	Industry $j$ demand for capital
$KDE_t$ :	Demand for capital by the electricity sectors
$IT_t$ :	Total investment expenditures
$PK_t$ :	Price of new capital
$SF_t$ :	Savings of businesses
$SG_t$ :	Government savings
$SH_{h,t}$ :	Savings of type $h$ households
$SROW_t$ :	Rest-of-the-world savings
$\delta_j$ :	Depreciation rate of capital in industry $j$
$\delta^E$ :	Depreciation rate of capital in electricity sector
$\delta_{j,t}^{KCC}$ :	Depreciation due to climate change in industry $j$

The supply of every commodity by local producers must be equal to domestic demand for that commodity produced locally (equation EQ6), and supply to the export market of each good must be matched by demand (equation EQ7).

$$\text{EQ6. } DS_{i,t} = DD_{i,t}$$

where

$DD_{i,t}$ :	Domestic demand for commodity $i$ produced locally
$DS_{i,t}$ :	Supply of commodity $i$ to the domestic market

## 7. Gross domestic product and aggregates

GDP at basic prices is equal to payments made to factors, plus taxes on production (equation A1). GDP at market prices exceeds GDP at basic prices by exactly the amount of taxes on products and imports (equation A2).

$$\text{A1. } GDP_t^{BP} = \sum_j PVA_{j,t} VA_{j,t} + TIPT_t$$

$$\text{A2. } GDP_t^{MP} = GDP_t^{BP} + TPRCTS_t$$

where

$GDP_t^{BP}$ :	GDP at basic prices
$GDP_t^{MP}$ :	GDP at market prices
$PVA_{j,t}$ :	Price of industry $j$ value added
$TIPT_t$ :	Total government revenue from production taxes
$TPRCTS_t$ :	Total government revenue from taxes on products and imports
$VA_{j,t}$ :	Value added of industry $j$

Real household consumption (equation A3), real government expenditures (equation A4) and real gross fixed capital formation (equation A5) are computed from the nominal variables using the appropriate indexes (see 5.3). Real GDP at basic prices and at market prices are similarly calculated.

$$A3. CTH_{h,t}^{REAL} = \frac{CTH_{h,t}}{PIXCON_t}$$

$$A4. G_t^{REAL} = \frac{G_t}{PIXGVT_t}$$

$$A5. GFCF_t^{REAL} = \frac{GFCF_t}{PIXINV_t}$$

$$A6. GDP_t^{BP\_REAL} = \frac{GDP_t^{BP}}{PIXGDP_t}$$

$$A7. GDP_t^{MP\_REAL} = \frac{GDP_t^{MP}}{PIXCON_t}$$

where

$CTH_{h,t}$ :	Consumption budget of type $h$ households
$CTH_{h,t}^{REAL}$ :	Real consumption expenditures of household $h$
$G_t$ :	Current government expenditures on goods and services
$G_t^{REAL}$ :	Real government expenditures
$GDP_t^{BP\_REAL}$ :	Real GDP at basic prices
$GDP_t^{MP\_REAL}$ :	Real GDP at market prices
$GFCF_t$ :	Gross fixed capital formation
$GFCF_t^{REAL}$ :	Real gross fixed capital formation
$PIXCON_t$ :	Consumer price index
$PIXGDP_t$ :	GDP deflator
$PIXGVT_t$ :	Public expenditures price index
$PIXINV_t$ :	Investment price index

## 8. Dynamic

Dynamic assignments constitute the link from one period to the next. They fall into two categories: one set of statements update variables that grow at a constant rate per period; the other equations control the accumulation of capital (equations DY1-DY11).

Some constants in the model are assumed to grow following demographic projections. The population index in the model ( $X_t^{POP}$ ) grows at rate  $g_t^{POP}$ , with  $X_{2017}^{POP} = 1$ . We assume that minimum consumption and total labour supply follow these projections. For all other exogenous variables, we assume that they follow the expected real GDP trajectory. Similar to population, we set the GDP index ( $X_t^{GDP}$ ) to be equal to 1 for the first period and to grow at a rate  $g_t^{GDP}$ . If both rates are the same, then the model would follow a regular path, or a balanced growth path. An economy is said to follow a balanced growth path if all quantities grow at a constant rate, while relative prices remain constant.

Hence, for exogenous variables, he is the path each follows:

$$\begin{aligned}
 LS_{h,l,t} &= LS_{h,l}^O X_t^{POP} & C_{i,h,t}^{MIN} &= C_{i,h}^{MINO} X_t^{POP} \\
 CAB_t &= CAB^O X_t^{GDP} & G_t^{REAL} &= G^{REAL-O} X_t^{GDP} \\
 SDF_t &= SDF^O X_t^{GDP} & LS_t^{ROW} &= LS^{ROWO} X_t^{GDP} \\
 VSTK_t^{IN} &= VSTK^{INO} X_t^{GDP} & VSTK_t^{OUT} &= VSTK^{OUTO} X_t^{GDP}
 \end{aligned}$$

Intercept in the linear equations also grow following the GDP growth index and so are indexed transfers.

The stock of capital in industry  $j$  in period  $t + 1$  is equal to the stock of the preceding period, minus depreciation, plus the volume of new capital investment in the preceding period. The underlying time-structure is therefore that new capital comes on-line one period after the investment has been made.

The capital accumulation rule is given by equation DY1:

$$\text{DY1.} \quad KD_{j,t+1} = KD_{j,t}(1 - \delta_j - \delta_{j,t}^{KCC}) + IND_{j,t} \quad \forall j \neq ele$$

where

$KD_{j,t}$ :	Industry $j$ demand for capital
$IND_{j,t}$ :	Volume of new capital investment to industry $j$
$\delta_j$ :	Depreciation rate of capital in industry $j$
$\delta_{j,t}^{KCC}$ :	Depreciation due to climate change in industry $j$

For the accumulation of capital in the electricity sector, projected hydropower developments up until 2039 are imposed. Indeed, annual capacity growth is not linked to the investment made in it for one given year but is rather the result of investments sustained over several years. Thus, for the electricity sector only, both investment and capital stock are exogenous for the 2017-2039 period. The investment

required to achieve the realisation of additional hydropower infrastructure is financed through external funds and most of the resources required (workers, machinery, material, etc.) is expected to come from outside Bhutan, with a third of the resources required for the development of hydroelectric infrastructures to be provided domestically. Part of total savings in the economy is thus be devoted to these projects ( $IT_t^{ELE}$ ) and would not be available for other industries development. This amount is exogenous for the same period (2017-2039).

After this development phase, capital stock in the electricity sector increases following investment (equation DY2), which is set to cover the depreciation of infrastructures (equation DY3). Hence, overall capital stock remains at the same level for the 2039-2040 period, unless there is an impact from climate change, in which case, there is a one period lag in the reparation of the infrastructure. Of course, both electricity production during summer and winter uses the same infrastructures (equation DY9).

$$\begin{aligned}
 \text{DY2.} \quad & KDE_{t+1} = KDE_t(1 - \delta^E - \delta_{ELE,t}^{KCC}) + INDE_t \quad \forall t \geq 2039 \\
 \text{DY3.} \quad & INDE_t = KDE_t(\delta^E + \delta_{ELE,t-1}^{KCC}) \quad \forall t \geq 2039 \\
 \text{DY4.} \quad & IT_t^{ELE} = PK_t INDE_t \quad \forall t \geq 2039 \\
 \text{DY5.} \quad & KD_{ele} = KDE_t
 \end{aligned}$$

Where

$INDE_t$ :	Volume of new capital in the electricity sectors
$IT_t^{ELE}$ :	Investment expenditures using Bhutan resources
$KD_{ele,t}$ :	Demand for capital in the electricity sectors
$KDE_t$ :	Demand for capital by the electricity sectors
$PK_t$ :	Price of new capital
$\delta^E$ :	Depreciation rate of capital in electricity sector
$\delta_{j,t}^{KCC}$ :	Depreciation due to climate change in industry $j$

The volume of new capital invested in public sectors is assumed to be exogenous and to follow the real GDP index,  $IND_{pub,t} = IND_{pub}^O X_t^{GDP}$ .

For all other sectors, the allocation of new private capital between categories and industries follows a modified version of the Jung-Thorbecke (2001) investment demand specification. The volume of new capital allocated to business-sector industry  $bus$  is proportional to the existing stock of capital and the proportion varies according to the ratio of the rental rate to the user cost of that capital, which may be interpreted as Tobin's  $q$ . The user cost of capital (equation DY7) depends on the price of new capital (the replacement cost of capital), the rate of depreciation, and the rate of interest. The rate of interest appears in no other equation. It is merely the rationing device that modulates investment demand in order to maintain total private investment expenditure within the constraint imposed by equilibrium condition DY9. There are no actual payments in the model that depend on the interest rate.

$$\text{DY6.} \quad IND_{bus,t} = \phi_{bus} \left[ \frac{R_{bus,t}}{U_{bus,t}} \right]^{\sigma_{bus}} KD_{j,t} \quad \forall j \neq ele$$

with

$$\text{DY7.} \quad U_{j,t} = PK_t(\delta_j + \delta_{j,t}^{KCC} + IR_t)$$

where

$IND_{bus,t}$ :	Volume of new capital investment to industry <i>bus</i>
$IR_t$ :	Interest rate
$KD_{j,t}$ :	Industry <i>j</i> demand for capital
$PK_t$ :	Price of new capital
$U_{j,t}$ :	User cost of capital in industry <i>j</i>
$R_{j,t}$ :	Rental rate of industry <i>j</i> capital
$\delta_j$ :	Depreciation rate of capital in industry <i>j</i>
$\delta_{j,t}^{KCC}$ :	Depreciation due to climate change in industry <i>j</i>
$\phi_{bus}$ :	Scale parameter (allocation of investment to industries)
$\sigma_{bus}^{INV}$ :	Elasticity (investment demand)

Equation DY8 gives the prices of new capital, which follow from investment demand function D3, whose form implies that the production function of new capital is Cobb-Douglas<sup>7</sup>. This specification implies that the price of one unit of new capital stock is the same, regardless of the industry in which it is installed. That is why the variable  $PK_t$  has no other index than time index *t*:

$$\text{DY8.} \quad PK_t = \frac{1}{A^K} \prod_i \left[ \frac{PC_{i,t}}{\gamma_i^{INV}} \right]^{\gamma_i^{INV}}$$

where

$PC_{i,t}$ :	Purchaser price of composite commodity <i>i</i> (including all taxes and margins)
$PK_t$ :	Price of new capital
$A^K$ :	Scale parameter (price of new capital)
$\gamma_i^{INV}$ :	Share of commodity <i>i</i> in total investment expenditures

The sum of the different forms of investment expenditure must be equal to total GFCF. In other words, investment intended for the private sector is determined by what remains of GFCF once public and electricity investments have been made.

$$\text{DY9.} \quad IT_t^{PRI} = GFCF_t - IT_t^{PUB} - IT_t^{ELE}$$

with

$$\text{DY10.} \quad IT_t^{PUB} = PK_t \sum_{pub} IND_{pub,t}$$

$$\text{DY11.} \quad IT_t^{PRI} = PK_t \sum_{bus \neq ele} IND_{bus,t}$$

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<sup>7</sup> See DLRM2 Appendix B1

where

$GFCF_t$ :	Gross fixed capital formation
$IND_{j,t}$ :	Volume of new capital investment to industry $j$
$IT_t^{ELE}$ :	Investment expenditures using Bhutan resources
$IT_t^{PRI}$ :	Total private investment expenditures
$IT_t^{PUB}$ :	Total public investment expenditures
$PK_t$ :	Price of new capital

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## Appendix A: Sets, equations, variables and parameters

### A1. Sets

#### A1.1 Industries and commodities

- Industries are represented through set  $j, jj \in J = \{J_1, \dots, J_{33}\}$

Acronym	Correspondence with the supply and use tables 2017
1-AGRI	Crop and animal production, hunting and related service activities
2-FOREST	Forestry and logging
3-MINING	Mining and quarrying
4-FOOD	Manufacture of food products; beverages and tobacco products
5-TEXTILES	Manufacture of textiles; wearing apparel and leather and related products
6-WOOD	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
7-PAPER	Manufacture of paper and paper products; Printing and reproduction of recorded media; Manufacture of rubber and plastics products
8-PLASTIC	Manufacture of Rubber and Plastic
9-METAL	Manufacture of basic metals; Manufacture of fabricated metal products, except machinery and equipment; computer, electronic and optical products; electrical equipment; machinery and equipment n.e.c.
10-FURNIT	Manufacture of furniture
11-MINPROD	Manufacture of other non-metallic mineral products
12-OTHMAN	Other manufacturing, n.e.c. and repair and installation of M&E
13-ELE_SUM	Electricity summer (May to October)
13-ELE_WIN	Electricity winter (November to April)
14-UTILIT	Water collection, treatment and supply; Sewerage; waste collection, treatment and disposal activities; Remediation activities
15-CONSTR	Construction of buildings; Civil engineering; Specialized construction activities
16-TRADE	Wholesale and retail trade; repair of motor vehicles and motorcycles
17-TLAND	Land Transport
18-TAIR	Air Transport
19-STORAGE	Storage
20-POST	Postal and courier services
21-HOT_REST	Accommodation and food service activities
22-CULTURE	Publishing activities; Motion picture, video and television programme production, sound recording and music publishing activities; Programming and broadcasting activities
23-COMM	Telecommunication
24-INFOR	Computer programming, consultancy and related activities; information service activities
25-FINAN	Financial service activities, except insurance and pension funding
26-INSUR	Insurance and reinsurance; Pension funding; Activities auxiliary to financial services and insurance activities
27-RESTATE	Real estate activities
28-OTHSER	Professional, scientific and technical activities; Administrative and support service activities
29-PUBADM	Public administration and defence; compulsory social security
30-EDUC	Education
31-HEALTH	Human health and social work activities
32-ART	Arts, entertainment and recreation

- Public sectors:  $pub \in PUB \subset J = \{29 - PUBADM, 30 - EDUC, 31 - HEALTH\}$
- Private sectors:  $bus \in BUS \subset J; BUS \cap PUB = \emptyset$
- Commodities are represented using set  $i, ij \in I = \{I_1, \dots, I_{49}\}$

Acronym	Correspondence with the supply and use tables 2017
1-CERE	Cereals and pulses
2-VEGE	Vegetables
3-FRUIT	Fruit and nuts
4-OTHAGR	Other products of agriculture, horticulture and market gardening, n.e.c
5-ROOT	Edible roots and tubers with high starch or inulin content
6-ANIM	Live animals and animal products (excluding meat)
7-FOREST	Forestry and logging products
8-FISH	Fish and other fishing products
9-FUELS	Coal and lignite; peat; Crude petroleum and natural gas
10-STONE	Stone, sand and clay
11-OTHMIN	Other minerals, n.ec.
12a-UTILIT	Steam and hot water; Natural water
12-ELE_SUM	Electricity summer (May to October)
12-ELE_WIN	Electricity winter (November to April)
13-FOOD	Meat, fish, fruit, vegetables, oils and fats; Dairy products and egg products
14-OTHFOOD	Grain mill products, starches and starch products; other food products
15-BEVTOB	Beverages; Tobacco products
16-TEXTILES	Yarn and thread; woven and tufted textile fabrics; Textile articles other than apparel: wearing apparel and lather products
17-WOOD	Products of wood, cork, straw and plaiting materials; pulp paper and paper products; printed matters and related articles
18-CHEMICALS	Basic chemicals; Other chemical products; man-made fibres
19-PLASTIC	Rubber and plastics products
20-MINPROD	Glass and glass products and other non-metallic products n.e.c.
21-FURNIT	Furniture
22-OTHGDS	Other transportable goods n.ec.
23-BMETAL	Basic metals
24-FMETAL	Fabricated metal products, except machinery and equipment
25-GENMC	General-purpose machinery
26-SPEMC	Special-purpose machinery
27-OFFMC	Office, accounting and computing machinery
28-ELEMC	Electrical machinery and apparatus
29-COMEQ	Radio, television and communication equipment and apparatus
30-MEDEQ	Medical appliances, precision and optical instruments, watches and clocks
31-VEHIC	Transport Equipment, Parts and Accessories of Motor Vehicles
32-OTHMAN	Manufacturing n.e.c
33-CONSTR	Construction; Construction services
34-TRADE	Wholesale trade services: Retail trade services
35-HOT_REST	Accommodation, food and beverage services
36-TLAND	Land Transport
37-TAIR	Air transport
38-STORAGE	Storage and warehousing services
39-POST	Postal and courier services
40-FINAN	Financial and related services
41-RESTATE	Real estate services
42-RENTAL	Leasing or rental services without operator
43-OTHSER	Other business and production services n.e.c.
44-TELCOM	Telecommunications, broadcasting and information supply services

<b>45-PUBADM</b>	Public administration and other services provided to the community as a whole; compulsory social security services
<b>46-EDUC</b>	Education services
<b>47-HEALTH</b>	Human health and social care services
<b>48-ARTCULT</b>	Recreational, Cultural, Sporting and Other services

## A1.2 Factors of production

- Labor categories:  $l \in L = \{L_{SAL}, L_{SEM}\}$  representing salaried and self-employed workers respectively.

## A1.3 Agents

- Household categories:  $h, hj \in H \subset AG = \{H_{HURB}, H_{HRUR}\}$  representing urban and rural households respectively.
- All agents:  $ag, agj \in AG = H \cup \{FIRM, TOUR, GVT, ROW\} = \{H_{HURB}, H_{HRUR}, FIRM, TOUR, GVT, ROW\}$  where *FIRM* represents firms, *TOUR* tourists, *GVT* the government and *ROW* the rest of the World.
- Non-governmental agent:  $agn_g \in AG = \{H_{HURB}, H_{HRUR}, FIRM, TOUR, ROW\}$
- Domestic agents:  $agd \in AG = \{H_{HURB}, H_{HRUR}, FIRM, TOUR, GVT\}$

## A1. Equations

### A1.1 Production

- X1.  $VA_{j,t} = v_j XST_{j,t}$
- X2.  $CI_{j,t} = io_j XST_{j,t}$
- X3.  $VA_{j,t} = CCF_{j,t} TFP_t B_j^{VA} \left[ \beta_j^{VA} LDC_{j,t}^{-\rho_j^{VA}} + (1 - \beta_j^{VA}) KD_{j,t}^{-\rho_j^{VA}} \right]^{-\frac{1}{\rho_j^{VA}}}$
- X4.  $LDC_{j,t} = \left[ \frac{\beta_j^{VA}}{(1 - \beta_j^{VA})} \frac{R_{j,t}}{WC_{j,t}} \right]^{\sigma_j^{VA}} KD_{j,t}$
- X5.  $LDC_{j,t} = B_j^{LD} \left[ \sum_l \beta_{l,j}^{LD} LD_{l,j,t}^{-\rho_j^{LD}} \right]^{-\frac{1}{\rho_j^{LD}}}$
- X6.  $LD_{l,j,t} = \left[ \frac{\beta_{l,j}^{LD} WC_{j,t}}{W_{l,t}} \right]^{\sigma_j^{LD}} (B_j^{LD})^{\sigma_j^{LD} - 1} LDC_{j,t}$
- X7.  $DI_{i,j,t} = DUMMY_j [ADJ_i aij_{i,j} CI_{j,t}] + (1 - DUMMY_j) [aij_{i,j} CI_{j,t}]$

### A1.2 Producer supplies of products and international trade

- IX1.  $XST_{j,t} = B_j^{XT} \left[ \sum_i \beta_{j,i}^{XT} XS_{j,i,t}^{\rho_j^{XT}} \right]^{\frac{1}{\rho_j^{XT}}}$
- IX2.  $XS_{j,i,t} = \frac{XST_{j,t}}{(B_j^{XT})^{1 + \sigma_j^{XT}}} \left[ \frac{P_{i,t}}{\beta_{j,i}^{XT} PT_{j,t}} \right]^{\sigma_j^{XT}}$
- IX3.  $XSI_{i,t} = \sum_j XS_{i,j,t} + VSTK_{i,t}^{OUT}$
- IX4.  $XSI_{i,t} = B_i^X \left[ \beta_i^X EX_{i,t}^{\rho_i^X} + (1 - \beta_i^X) DS_{i,t}^{\rho_i^X} \right]^{\frac{1}{\rho_i^X}} \forall i \neq ele$
- IX5.  $EX_{i,t} = \left[ \frac{1 - \beta_i^X}{\beta_i^X} \frac{PE_{i,t}}{PL_{i,t}} \right]^{\sigma_i^X} DS_{i,t} \forall i \neq ele$

$$IX6. XSI_{ele,t} = EX_{ele,t} + DS_{ele,t}$$

$$IX7. EX_{12-ELE\_WIN',t} = sh_t^{EX} XSI_{12-ELE\_WIN',t}$$

$$IX8. IM_{12-ELE\_WIN',t} = Q_{12-ELE\_WIN',t} - DD_{12-ELE\_WIN',t}$$

$$IX9. Q_{i,t} = B_i^M \left[ \beta_i^M IM_{i,t}^{-\rho_i^M} + (1 - \beta_i^M) DD_{i,t}^{-\rho_i^M} \right]^{\frac{-1}{\rho_i^M}} \forall i \neq ele$$

$$IX10. IM_{i,t} = \left[ \frac{\beta_i^M PD_{i,t}}{1 - \beta_i^M PM_{i,t}} \right]^{\sigma_i^M} DD_{i,t} \forall i \neq ele$$

### A1.3 Demand

$$D1. PC_{i,t} C_{i,h,t} = PC_{i,t} C_{i,h,t}^{MIN} + \gamma_{i,h}^{LES} (CTH_{h,t} - \sum_{ij} PC_{ij,t} C_{ij,h,t}^{MIN})$$

$$D2. GFCF_t = IT_t - \sum_i PC_{i,t} VSTK_{i,t}^{IN} + \sum_i P_{i,t} VSTK_{i,t}^{OUT}$$

$$D3. PC_{i,t} INV_{i,t} = \gamma_i^{INV} GFCF_t$$

$$D4. PC_{i,t} CG_{i,t} = \gamma_i^{GVT} G_t$$

$$D5. DIT_{i,t} = \sum_j DI_{i,j,t}$$

$$D6. MRGN_{i,t} = \sum_{ij} tmr g_{i,ij} DD_{ij,t} + \sum_{ij} tmr g_{i,ij} IM_{ij,t}$$

$$D7. PC_{i,t} CT_i = \gamma_i^{TOUR} CTT_t$$

### A1.4 Income and savings

#### A1.4.1 Households

$$H1. YH_{h,t} = YHL_{h,t} + YHTR_{h,t}$$

$$H2. YHL_{h,t} = \sum_l (W_{l,t} \sum_l LS_{h,l,t}^B (1 - unr_{h,l,t})) + e_t \sum_l W_{l,t}^W LS_{h,l,t}^W$$

$$H3. LS_{h,l,t} = B_{h,l}^{LS} \left[ \beta_{h,l}^{LS} LS_{h,l,t}^{\rho_{h,l}^{LS}} + (1 - \beta_{h,l}^{LS}) LS_{h,l,t}^{W\rho_{h,l}^{LS}} \right]^{\frac{1}{\rho_{h,l}^{LS}}}$$

$$H4. LS_{h,l,t}^B = \left[ \frac{1 - \beta_{h,l}^{LS} W_{l,t} (1 - unr_{h,l,t})}{\beta_{h,l}^{LS} e_t W_{l,t}^W} \right]^{\sigma_{h,l}^{LS}} LS_{h,l,t}^W$$

$$H5. A_{h,l}^{UN} unr_{h,l,t} = \left[ \frac{W_{l,t}}{PIXCON_t} \right]^{\frac{1}{\sigma_{h,l}^{UN}}}$$

$$H6. YHTR_{h,t} = \sum_{ag} TR_{h,ag,t}$$

$$H7. YDH_{h,t} = YH_{h,t} - TDH_{h,t} - TR_{gvt,h,t}$$

$$H8. CTH_{h,t} = YDH_{h,t} - SH_{h,t} - \sum_{agng} TR_{agng,h,t}$$

$$H9. SH_{h,t} = PIXCON_t sh0_{h,t} + sh1_{h,t} YDH_{h,t}$$

#### A1.4.2 Tourists

$$TO1. YT_t = TR_{tour,row,t}$$

$$TO2. CTT_t = YT_t - SDF_t$$

#### A1.4.3 Firms

$$F1. YF_t = YFK_t + YFTR_t$$

$$F2. YFK_t = (\sum_j R_{j,t} KD_{j,t} - ROY_{j,t}) - DEP_t$$

$$F3. YFTR_t = \sum_{ag} TR_{FIRM,ag,t}$$

$$F4. YDF_t = YF_t - TDF_t$$

$$F5. SF_t = YDF_t - \sum_{ag} TR_{ag,FIRM,t}$$

#### A1.4.4 Government

- G1.  $YG_t = TPRCTS_t + TIPT_t + TDHT_t + TDF_t + YGR_t + YGTR_t$   
G2.  $TPRCTS_t = TICT_t + TIMT_t + TIXT_t$   
G3.  $TICT_t = \sum_i TIC_{i,t}$   
G4.  $TIC_{i,t} = ttic_{i,t} \left\{ (PL_{i,t} + \sum_{ij} PC_{ij,t} tmr g_{ij,i}) DD_{i,t} + \left( (1 + ttim_{i,t}) PWM_{i,t} e_t + \sum_{ij} PC_{ij,t} tmr g_{ij,i} \right) IM_{i,t} \right\}$   
G5.  $TIMT_t = \sum_i TIM_{i,t}$   
G6.  $TIM_{i,t} = ttim_{i,t} PWM_{i,t} e_t IM_{i,t}$   
G7.  $ttim_{i,t} = cduy_{i,t} + stax_{i,t} + gtax_{i,t}$   
G8.  $TIXT_t = \sum_i TIX_{i,t}$   
G9.  $TIX_{i,t} = ttix_{i,t} PE_{i,t} EX_{i,t}$   
G10.  $TIPT_t = \sum_j TIP_{j,t}$   
G11.  $TIP_{j,t} = ttip_{j,t} PP_{j,t} XST_{j,t}$   
G12.  $TDHT_t = \sum_h TDH_{h,t}$   
G13.  $TDH_{h,t} = PIXCON_t ttdh0_{h,t} + ttdh1_{h,t} W_{SAL,t} LS_{h,SAL,t}^B (1 - unr_{h,SAL,t})$   
G14.  $TDF_t = PIXCON_t ttdf0_t + ttdf1_t YFK_t$   
G15.  $ROY_{j,t} = \lambda_j^{RKG} R_{j,t} KD_{j,t}$   
G16.  $YGR_t = \sum_j R_j ROY_{j,t} + SDF_t$   
G17.  $YGTR_t = \sum_{agn} TR_{gvt,agn,t}$   
G18.  $SG_t = YG_t - \sum_{agn} TR_{agn,gvt,t} - G_t$

#### A1.4.5 Rest of the world

- W1.  $YROW_t = e_t \sum_i PWM_{i,t} IM_{i,t} + \sum_{agd} TR_{row,agd,t} + \sum_l W_{l,t} LS_{l,t}^{ROW}$   
W2.  $SROW_t = YROW_t - e_t \sum_i PWX_{i,t} EX_{i,t} - \sum_{agd} TR_{agd,row,t} - e_t \sum_{h,l} W_{l,t}^W LS_{h,l,t}^W$   
W3.  $SROW_t = -CAB_t$

#### A1.4.6 Transfers

- T1.  $TR_{agn,h,t} = \lambda_{agn,h}^{TR} YDH_{h,t}$   
T2.  $TR_{gvt,h,t} = PIXCON_t tr0_{h,t} + tr1_{h,t} YH_{h,t}$   
T3.  $TR_{ag,FIRM,t} = \lambda_{ag,FIRM}^{TR} YDF_t$   
T4.  $TR_{agd,gvt,t} = PIXCON_t TR_{agd,gvt,t}^0 X_t^{GDP}$   
T5.  $TR_{row,gvt,t} = PIXCON_t TR_{row,gvt,t}^0 X_t^{GDP} + INT_t^{ELE}$   
T6.  $TR_{agd,row,t} = PIXCON_t TR_{agd,row,t}^0 X_t^{GDP}$   
T7.  $TR_{ag,tour,t} = PIXCON_t TR_{ag,tour,t}^0 X_t^{GDP}$

### A1.5 Prices

#### A1.5.1 Production

- P1.  $PP_{j,t} = \frac{PVA_{j,t} VA_{j,t} + PCI_{j,t} CI_{j,t}}{XST_{j,t}}$   
P2.  $PT_{j,t} = (1 + ttip_{j,t}) PP_{j,t}$

$$P3. PCI_{j,t} = \frac{\sum_i PC_{i,t} DI_{i,j,t}}{CI_{j,t}}$$

$$P4. PVA_{j,t} = \frac{WC_{j,t} LDC_{j,t} + R_{j,t} KD_{j,t}}{VA_{j,t}}$$

### A1.5.2 International trade

$$P5. P_{i,t} = \frac{PE_{i,t} EX_{i,t} + PL_{i,t} DS_{i,t}}{XSI_{i,t}}$$

$$P6. e_t PWX_{i,t} = PE_{i,t} (1 - tti_{i,t})$$

$$P7. PD_{i,t} = (1 + tti_{i,t}) (PL_{i,t} + \sum_{ij} PC_{i,t} tmrg_{ij,i})$$

$$P8. PM_{i,t} = (1 + tti_{i,t}) \left( (1 + tim_{i,t}) e_t PWM_{i,t} + \sum_{ij} PC_{ij,t} tmrg_{ij,i} \right)$$

$$P9. PC_{i,t} = \frac{PM_{i,t} IM_{i,t} + PD_{i,t} DD_{i,t}}{Q_{i,t}}$$

### A1.5.3 Price indexes

$$P1. PIXGDP_t = \sqrt{\frac{\sum_j \left( PVA_{j,t} + \frac{TIP_{j,t}}{VA_{j,t}} \right) VA_j^O \sum_j (PVA_{j,t} VA_{j,t} + TIP_{j,t})}{\sum_j (PVA_j^O VA_j^O + TIP_j^O) \sum_j \left( PVA_j^O + \frac{TIP_j^O}{VA_j^O} \right) VA_{j,t}}}$$

$$P2. PIXCON_t = \frac{\sum_i PC_{i,t} \sum_h C_{i,h}^O}{\sum_{ij} PC_{ij}^O \sum_h C_{ij,h}^O}$$

$$P3. PIXINV_t = \prod_i \left( \frac{PC_{i,t}}{PC_i^O} \right)^{Y_i^{INV}}$$

$$P4. PIXGVT_t = \prod_i \left( \frac{PC_{i,t}}{PC_i^O} \right)^{Y_i^{GVT}}$$

### A1.6 Equilibrium

$$EQ1. Q_{i,t} = \sum_h C_{i,h,t} + CG_{i,t} + CT_{i,t} + INV_{i,t} + VSTK_{i,t}^{IN} + DIT_{i,t} + MRGN_{i,t}$$

$$EQ2. \sum_j LD_{l,j,t} = \sum_h LS_{h,l,t}^B (1 - unr_{h,l,t}) + LS_{l,t}^{ROW}$$

$$EQ3. \sum_{j \neq ele} KD_{j,t} + KDE_t = KS_t$$

$$EQ4. IT_t = \sum_h SH_{h,t} + SF_t + SG_t + SROW_t + DEP_t$$

$$EQ5. DEP_t = \sum_{j \neq ele} (\delta_j + \delta_{j,t}^{CC}) KD_{j,t} PK_t + (\delta^E + \delta_{ele,t}^{CC}) KDE_t PK_t$$

$$EQ6. DS_{i,t} = DD_{i,t}$$

### A1.7 Gross domestic product and other economic aggregates

$$A1. GDP_t^{BP} = \sum_j PVA_{j,t} VA_{j,t} + TIPT_t$$

$$A2. GDP_t^{MP} = GDP_t^{BP} + TPRCTS_t$$

$$A3. CTH_{h,t}^{REAL} = \frac{CTH_{h,t}}{PIXCON_t}$$

$$A4. G_t^{REAL} = \frac{G_t}{PIXGVT_t}$$

$$A5. GFCF_t^{REAL} = \frac{GFCF_t}{PIXINV_t}$$

$$A6. GDP_t^{BP\_REAL} = \frac{GDP_t^{BP}}{PIXGDP_t}$$

$$A7. GDP_t^{MP\_REAL} = \frac{GDP_t^{MP}}{PIXCON_t}$$

### A1.8 Dynamic

$$\begin{aligned}
 \text{DY1.} \quad & KD_{j,t+1} = KD_{j,t}(1 - \delta_j - \delta_{j,t}^{KCC}) + IND_{j,t} \quad \forall j \neq ele \\
 \text{DY2.} \quad & KDE_{t+1} = KDE_t(1 - \delta^E - \delta_{ELE,t}^{KCC}) + INDE_t \quad \forall t \geq 2039 \\
 \text{DY3.} \quad & INDE_t = KDE_t(\delta^E + \delta_{ELE,t-1}^{KCC}) \quad \forall t \geq 2039 \\
 \text{DY4.} \quad & IT_t^{ELE} = PK_t INDE_t \quad \forall t \geq 2039 \\
 \text{DY5.} \quad & KD_{ele} = KDE_t \\
 \text{DY6.} \quad & IND_{bus,t} = \phi_{bus} \left[ \frac{R_{bus,t}}{U_{bus,t}} \right]^{\sigma_{bus}} KD_{j,t} \quad \forall j \neq ele \\
 \text{DY7.} \quad & U_{j,t} = PK_t(\delta_j + \delta_{j,t}^{KCC} + IR_t) \\
 \text{DY8.} \quad & PK_t = \frac{1}{A^K} \prod_i \left[ \frac{PC_{i,t}}{Y_i^{INV}} \right]^{Y_i^{INV}} \\
 \text{DY9.} \quad & IT_t^{PRI} = GFCF_t - IT_t^{PUB} - IT_t^{ELE} \\
 \text{DY10.} \quad & IT_t^{PUB} = PK_t \sum_{pub} IND_{pub,t} \\
 \text{DY11.} \quad & IT_t^{PRI} = PK_t \sum_{bus \neq ele} IND_{bus,t}
 \end{aligned}$$

### A1.9 Climate change

$$\text{CC1.} \quad CCF_{j,t+1} = CCF_{j,t} \{1 + \delta_{j,t+1}^{CC}\}$$

## A3. Variables

### A3.1 Endogenous variables

$C_{i,h,t}$ :	Consumption of commodity $i$ by type $h$ households
$CG_{i,t}$ :	Public consumption of commodity $i$ (volume)
$CI_{j,t}$ :	Total intermediate consumption of industry $j$
$CT_{i,t}$ :	Tourists purchases of commodity $i$
$CTH_{h,t}$ :	Consumption budget of type $h$ households
$CTH_{h,t}^{REAL}$ :	Real consumption expenditures of household $h$
$CTT_t$ :	Tourists budget net of sustainable development fee
$DD_{i,t}$ :	Domestic demand for commodity $i$ produced locally
$DEP_t$ :	Consumption of fixed capital
$DI_{i,j,t}$ :	Intermediate consumption of commodity $i$ by industry $j$
$DIT_{i,t}$ :	Total intermediate demand for commodity $i$
$DS_{i,t}$ :	Supply of commodity $i$ to the domestic market
$EX_{i,t}$ :	Quantity of product $i$ exported
$G_t$ :	Current government expenditures on goods and services
$GDP_t^{BP}$ :	GDP at basic prices
$GDP_t^{BP\_REAL}$ :	Real GDP at basic prices
$GDP_t^{MP}$ :	GDP at market prices
$GDP_t^{MP\_REAL}$ :	Real GDP at market prices
$GFCF_t$ :	Gross fixed capital formation
$GFCF_t^{REAL}$ :	Real gross fixed capital formation
$IM_{i,t}$ :	Quantity of product $i$ imported
$INDE_t$ :	Volume of new capital in the electricity sectors ( $t > 2039$ )
$IND_{bus,t}$ :	Volume of new capital investment to industry $bus$

$INV_{i,t}$ :	Final demand of commodity $i$ for investment purposes
$IR_t$ :	Interest rate
$IT_t$ :	Total investment expenditures
$IT_t^{ELE}$ :	Investment expenditures using Bhutan resources ( $t > 2039$ )
$IT_t^{PRI}$ :	Total private investment expenditures
$IT_t^{PUB}$ :	Total public investment expenditures
$KD_{j,t}$ :	Industry $j$ demand for capital
$KDE_t$ :	Demand for capital by the electricity sectors ( $t > 2039$ )
$KS_t$ :	Total supply of capital
$LD_{l,j,t}$ :	Demand for type $l$ labour by industry $j$
$LDC_{j,t}$ :	Industry $j$ demand for composite labour
$LS_{h,l,t}^B$ :	Supply of type $l$ labour by type $h$ household in Bhutan
$LS_{h,l,t}^W$ :	Supply of type $l$ labour by type $h$ household outside Bhutan
$MARGN_{i,t}$ :	Demand for commodity $i$ as a trade or transport margin
$P_{i,t}$ :	Basic price of commodity $i$
$PC_{i,t}$ :	Purchaser price of composite commodity $i$ (including all taxes and margins) $\forall i \neq ele$
$PCI_{j,t}$ :	Intermediate consumption price index of industry $j$
$PD_{i,t}$ :	Price of local product $i$ sold on the domestic market (including all taxes and margins)
$PK_t$ :	Price of new capital
$PL_{i,t}$ :	Price of local product $i$ (excluding all taxes on products) "
$PM_{i,t}$ :	Price of imported product $i$ (including all taxes and margins)
$PE_{i,t}$ :	Price received for exported commodity $i$ (excluding export taxes)
$PIXCON_t$ :	Consumer price index
$PIXGDP_t$ :	GDP deflator
$PIXGVT_t$ :	Public expenditures price index
$PIXINV_t$ :	Investment price index
$PP_{j,t}$ :	Industry $j$ unit cost excluding taxes on production
$PT_{j,t}$ :	Basic price of industry $j$ 's output
$PVA_{j,t}$ :	Price of industry $j$ value added
$Q_{i,t}$ :	Quantity demanded of composite commodity $i$
$R_{j,t}$ :	Rental rate of industry $j$ capital
$ROY_{j,t}$ :	Royalties paid by industry $j$
$SDF_t$ :	Sustainable development fee
$SF_t$ :	Savings of businesses
$SG_t$ :	Government savings
$SH_{h,t}$ :	Savings of type $h$ households
$SROW_t$ :	Rest-of-the-world savings
$TDF_t$ :	Income taxes of businesses
$TDH_{h,t}$ :	Income taxes of type $h$ households
$TDHT_t$ :	Total government revenue from household income taxes
$TIC_{i,t}$ :	Government revenue from indirect taxes on product $i$
$TICT_t$ :	Total government receipts of indirect taxes on commodities
$TIM_{i,t}$ :	Government revenue from import duties on product $i$
$TIMT_t$ :	Total government revenue from import duties
$TIP_{j,t}$ :	Government revenue from taxes on industry $j$ production
$TIPT_t$ :	Total government revenue from production taxes

$TIX_{i,t}$ :	Government revenue from export taxes on product $i$
$TIXT_t$ :	Total government revenue from export taxes
$TPRCTS_t$ :	Total government revenue from taxes on products and imports
$ttim_{i,t}$ :	Overall of tax rate on imports of commodity $i$
$TR_{ag,agj,t}$ :	Transfers from agent $agj$ to agent $ag$
$U_{j,t}$ :	User cost of capital in industry $j$
$unr_{h,l,t}$ :	Unemployment rate for type $l$ labour in region $h$
$VA_{j,t}$ :	Value added of industry $j$
$W_{l,t}$ :	Wage rate of type $l$ labour
$WC_{j,t}$ :	Wage rate of industry $j$ composite labour
$XS_{j,i,t}$ :	Industry $j$ production of commodity $i$
$XSI_{i,t}$ :	Total supply of commodity $i$
$XST_{j,t}$ :	Total aggregate output of industry $j$
$YDF_t$ :	Disposable income of businesses
$YDH_{h,t}$ :	Disposable income of type $h$ households
$YF_t$ :	Total income of businesses
$YFK_t$ :	Capital income of businesses
$YFTR_t$ :	Transfer income of businesses
$YG_t$ :	Total government income
$YGR_t$ :	Government capital income (royalties)
$YGTR_t$ :	Government transfer income
$YH_{h,t}$ :	Total income of type $h$ households
$YHL_{h,t}$ :	Labor income of type $h$ households
$YHTR_{h,t}$ :	Transfer income of type $h$ households
$YROW_t$ :	Rest-of-the-world income
$YT_t$ :	Total tourists budget

### A3.2 Exogenous variables

$ADJ_i$ :	Adjustment factor (greater electricity input)
$CAB_t$ :	Current account balance
$C_{i,h,t}^{MIN}$ :	Minimum consumption of commodity $i$ by type $h$ households
$e_t$ :	Exchange rate (numeraire)
$G_t^{REAL}$ :	Real government expenditures
$INDE_t$ :	Volume of new capital in the electricity sectors ( $t < 2039$ )
$IND_{pub,t}$ :	Volume of new capital investment to industry $pub$
$IT_t^{ELE}$ :	Investment expenditures using Bhutan resources ( $t < 2039$ )
$KD_{j,2017}$ :	Industry $j$ demand for capital
$KDE_t$ :	Demand for capital by the electricity sectors ( $t < 2039$ )
$LS_{l,h,t}$ :	Supply of type $l$ labour in region $h$
$LS_{l,t}^{ROW}$ :	Non-resident labour supply
$PC_{ele,t}$ :	Price of electricity
$PWM_{i,t}$ :	World price of imported product $i$ (expressed in foreign currency)
$PWX_{i,t}$ :	World price of exported product $i$ (expressed in foreign currency)
$TFP_t$ :	Total factor productivity
$VSTK_{i,t}^{IN}$ :	Inventory change of commodity $i$ (demand)
$VSTK_{i,t}^{OUT}$ :	Inventory change of commodity $i$ (supply)

$W_{l,t}^W$ : Wage rate of type  $l$  labour received outside Bhutan

#### Rates and intercepts (exogenous)

$cduty_{i,t}$ :	Rate of custom duties on imports of commodity $i$
$\delta_{j,t}^{CC}$ :	Change in productivity due to climate change
$\delta_{j,t}^{KCC}$ :	Depreciation due to climate change in industry $j$
$gtax_{i,t}$ :	Rate of green taxes on imports of commodity $i$
$stax_{i,t}$ :	Rate of sales taxes on imports of commodity $i$
$tr0_{gvt,h,t}$ :	Intercept (transfers by type $h$ households to government)
$tr1_{gvt,h,t}$ :	Marginal rate of transfers by type $h$ households to government
$ttdf0_t$ :	Intercept (income taxes of businesses)
$ttdf1_t$ :	Marginal income tax rate of businesses
$ttdh0_{h,t}$ :	Intercept (income taxes of type $h$ households)
$ttdh1_{h,t}$ :	Marginal income tax rate of type $h$ households
$ttic_{i,t}$ :	Tax rate on commodity $i$
$ttip_{j,t}$ :	Tax rate on the production of industry $j$
$ttix_{i,t}$ :	Export tax rate on exported commodity $i$
$sh0_{h,t}$ :	Intercept (type $h$ household savings)
$sh1_{h,t}$ :	Slope (type $h$ household savings)

#### A4. Parameters

$A^K$ :	Scale parameter (price of new capital)
$aij_{i,j}$ :	Input-output coefficient
$A_{h,l}^{UN}$ :	Scale parameter (wage curve)
$B_j^{LD}$ :	Scale parameter (CES – composite labour)
$B_{h,l}^{LS}$ :	Scale parameter (CET – labour supply)
$B_i^M$ :	Scale parameter (CES – composite commodity)
$B_j^{VA}$ :	Scale parameter (CES – value added)
$B_i^X$ :	Scale parameter (CET – exports and local sales)
$B_j^{XT}$ :	Scale parameter (CET – total output)
$\beta_{l,j}^{LD}$ :	Share parameter (CES – composite labour)
$\beta_{h,l}^{LS}$ :	Share parameter (CET – labour supply)
$\beta_i^M$ :	Share parameter (CES – composite commodity)
$\beta_j^{VA}$ :	Share parameter (CES – value added)
$\beta_i^X$ :	Share parameter (CET – exports and local sales)
$\beta_{j,i}^{XT}$ :	Share parameter (CET – total output)
$DUMMY_j$ :	Dummy variable (1 if the electricity intensity adjusts, 0 if not)
$\delta_j$ :	Depreciation rate of capital in industry $j$
$\delta^E$ :	Depreciation rate of capital in electricity sector
$\gamma_i^{GVT}$ :	Share of commodity $i$ in total current public expenditures on goods and services
$\gamma_i^{INV}$ :	Share of commodity $i$ in total investment expenditures
$\gamma_{i,h}^{LES}$ :	Marginal share of commodity $i$ in type $h$ household consumption budget
$\gamma_i^{TOUR}$ :	Share of commodity $i$ in total tourists expenditures
$io_j$ :	Coefficient (Leontief – intermediate consumption)

$\lambda_j^{RKG}$ :	Share of capital income (royalties) received by government
$\lambda_{ag,agj}^{TR}$ :	Share parameter (transfer functions)
$\phi_{bus}$ :	Scale parameter (allocation of investment to industries)
$\rho_j^{LD}$ :	Elasticity parameter (CES – composite labour)
$\rho_{h,l}^{LS}$ :	Elasticity parameter (CET – labour supply)
$\rho_i^M$ :	Elasticity parameter (CES – composite commodity)
$\rho_j^{VA}$ :	Elasticity parameter (CES – value added)
$\rho_i^X$ :	Elasticity parameter (CET – exports and local sales)
$\rho_j^{XT}$ :	Elasticity parameter (CET – total output)
$\sigma_{bus}^{INV}$ :	Elasticity (investment demand)
$\sigma_j^{LD}$ :	Elasticity of substitution (CES – composite labour)
$\sigma_{h,l}^{LS}$ :	Elasticity of transformation (CET – labour supply)
$\sigma_i^M$ :	Elasticity of substitution (CES – composite commodity)
$\sigma_{h,l}^{UN}$ :	Elasticity (wage curve)
$\sigma_j^{VA}$ :	Elasticity of transformation (CES – value added)
$\sigma_i^X$ :	Elasticity of transformation (CET – exports and local sales)
$\sigma_j^{XT}$ :	Elasticity of transformation (CET – total output)
$sh_t^{EX}$ :	Share of exports in overall production (winter)
$tmargin_{ij,i}$ :	Rate of margin $ij$ applied to commodity $i$
$v_j$ :	Coefficient (Leontief – value added)
$X_t^{GDP}$ :	Real GDP index (2017=1)

## Appendix B: Elasticities

Most of the parameters in the model can be calibrated using the data from the SAM. However, for some functional forms used, we need to find information in the literature. The following tables present values of elasticity used in other CGE models.

### TRADE ELASTICITIES

**TABLE 1: ARMINGTON ELASTICITIES**

*(between imports and domestic production)*

Dorji (2023) / Suvannaphakdy and Toyoda (2019) – (values for Laos)	
All commodities	0.84
Bhattacharya et al (2018)	
Agriculture	2.28
Mining	0.65
Metals	0.65
Manufacturing	0.91
Petroleum product	0.61
Other	0.99
GTAP model – Hertel and van der Mensbrugge (2024)	
Paddy rice	5.05
Wheat	4.45
Cereal grains nec	1.30
Vegetables, fruit, nuts	1.85
Oil seeds	2.45
Sugar cane, sugar beet	2.70
Plant-based fibers	2.50
Crops nec	3.25
Bovine cattle, sheep and goats, horses	2.00
Animal products nec	1.30
Raw milk	3.65
Wool, silk-worm cocoons	6.45
Forestry	2.50
Fishing	1.25
Coal	3.05
Oil	5.20
Gas	17.20
Minerals nec	0.90
Bovine meat products	3.85
Meat products nec	4.40
Vegetable oils and fats	3.30
Dairy products	3.65
Processed rice	2.60
Sugar	2.70
Food products nec	2.00
Beverages and tobacco products	1.15
Textiles	3.75
Wearing apparel	3.70

Leather products	4.05
Wood products	3.40
Paper products, publishing	2.95
Petroleum, coal products	2.10
Chemical pharmaceutical Rubber and plastic products	3.30
Mineral products nec	2.90
Ferrous metals	2.95
Metals nec	4.20
Metal products	3.75
Computer, electronic and optical products	4.40
Electrical equipment	4.40
Machinery and equipment nec	4.05
Motor vehicles and parts	2.80
Transport equipment nec	4.30
Manufactures nec	3.75
Electricity, gas and water	2.80
Other	1.90

**TABLE 2: CET ELASTICITIES**

*(between exports and domestic production)*

Dorji (2023) / Suvannaphakdy and Toyoda (2019) – (value for Myanmar)	
All commodities	0.24

**PRODUCTION ELASTICITIES**

**TABLE 3: CES ELASTICITIES**

*(between labour and capital)*

Dorji (2023) / Mallick (2012) – (value for ?)	
All industries	0.84
Bhattacharya et al (2018)	
Agriculture	0.78
Mining	0.96
Metal	0.96
Manufacturing	0.96
Petroleum product	0.96
Electricity	0.91
Consumer retail	0.39
Other	0.59
GTAP model – Hertel and van der Mensbrugghe (2024) – For all countries	
Crops and animal production	0.26
Raw milk	0.26
Wool, silk-worm cocoons	0.26
Forestry	0.20
Fishing	0.20
Mining	0.20
Food products	1.12

Beverages and tobacco products	1.12
Manufacturing	1.26
Electricity, gas and water	1.26
Construction	1.40
Trade	1.68
Accommodation, Food and service activities	1.68
Transport and warehousing	1.68
Other services	1.26

## LES PARAMETERS

**TABLE 4: INCOME ELASTICITIES FOR DIFFERENT FOOD SUBCATEGORIES**

Minten, B. and Dukpa, C. (2010)		
	Rural	Urban
cereals/pulses	0.370	0.249
dairy	0.608	0.322
fish/meat	0.552	0.372
fruit	0.497	0.320
vegetables	0.401	0.246
beverages	0.497	0.378
oil	0.339	0.263
spices	0.345	0.290
other food	0.970	0.653

**TABLE 5: FRISCH PARAMETER AND INCOME ELASTICITY VALUES**

Shutes et al 2023	
Frisch	-2.5
Income elasticities	
Agriculture, livestock, and processed food	0.4
Forestry, mining and manufacturing	1.5
Fuels and electricity	2.2
Construction	1.2
Utilities, trade, transport, communications, and services	2.2

Wage-curve elasticity: -0.07 - Nijkamp and Poot (2005)

**TABLE 6: ELASTICITY USED IN THE MODEL – PER INDUSTRY**

Acronym	$\sigma^{VA}$	$\sigma^{LD\delta}$	$\sigma^{XT}$
1-AGRI	0.78	1.56	1.5
2-FOREST	0.78	1.56	1.5

<sup>8</sup> It is common in CGE models to double the elasticity value as we go down a nested CES function.

3-MINING	0.96	1.92	1.5
4-FOOD	0.96	1.92	1.5
5-TEXTILES	0.96	1.92	1.5
6-WOOD	0.96	1.92	1.5
7-PAPER	0.96	1.92	1.5
8-PLASTIC	0.96	1.92	1.5
9-METAL	0.96	1.92	1.5
10-FURNIT	0.96	1.92	1.5
11-MINPROD	0.96	1.92	1.5
12-OTHMAN	0.96	1.92	1.5
13-ELE_GAS	0.91	1.82	1.5
14-UTILIT	0.59	1.18	1.5
15-CONSTR	0.59	1.18	1.5
16-TRADE	0.39	0.78	1.5
17-TLAND	0.59	1.18	1.5
18-TAIR	0.59	1.18	1.5
19-STORAGE	0.59	1.18	1.5
20-POST	0.59	1.18	1.5
21-HOT_REST	0.59	1.18	1.5
22-CULTURE	0.59	1.18	1.5
23-COMM	0.59	1.18	1.5
24-INFOR	0.59	1.18	1.5
25-FINAN	0.59	1.18	1.5
26-INSUR	0.59	1.18	1.5
27-RESTATE	0.59	1.18	1.5
28-OTHSER	0.59	1.18	1.5
29-PUBADM	0.59	1.18	1.5
30-EDUC	0.59	1.18	1.5
31-HEALTH	0.59	1.18	1.5
32-ART	0.59	1.18	1.5

TABLE 7: ELASTICITY USED IN THE MODEL – PER COMMODITY

Acronym	$\sigma^M$	$\sigma^X$	Income elasticity	
			HRUR	HURB
1-CERE	2.28	0.24	0.37	0.249
2-VEGE	2.28	0.24	0.401	0.246
3-FRUIT	2.28	0.24	0.497	0.32
4-OTHAGR	2.28	0.24	0.97	0.653
5-ROOT	2.28	0.24	0.97	0.653
6-ANIM	2.28	0.24	0.552	0.372
7-FOREST	2.28	0.24	1.5	1.5
8-FISH	2.28	0.24	0.552	0.372
9-FUELS	0.65	0.24	2.2	2.2
10-STONE	0.65	0.24	1.5	1.5
11-OTHMIN	0.65	0.24	1.5	1.5
12-UTILIT	0.99	2	2.2	2.2
13-FOOD	0.91	0.24	0.97	0.653

14-OTHFOOD	0.91	0.24	0.97	0.653
15-BEVTOB	0.91	0.24	0.497	0.378
16-TEXTILES	0.91	0.24	1.5	1.5
17-WOOD	0.91	0.24	1.5	1.5
18-CHEMICALS	0.91	0.24	1.5	1.5
19-PLASTIC	0.91	0.24	1.5	1.5
20-MINPROD	0.91	0.24	1.5	1.5
21-FURNIT	0.91	0.24	1.5	1.5
22-OTHGDS	0.91	0.24	1.5	1.5
23-BMETAL	0.65	0.24	1.5	1.5
24-FMETAL	0.65	0.24	1.5	1.5
25-GENMC	0.91	0.24	1.5	1.5
26-SPEMC	0.91	0.24	1.5	1.5
27-OFFMC	0.91	0.24	1.5	1.5
28-ELEMC	0.91	0.24	1.5	1.5
29-COMEQ	0.91	0.24	1.5	1.5
30-MEDEQ	0.91	0.24	1.5	1.5
31-VEHIC	0.91	0.24	1.5	1.5
32-OTHMAN	0.91	0.24	1.5	1.5
33-CONSTR	0.99	0.24	1.2	1.2
34-TRADE	0.99	0.24	2.2	2.2
35-HOT_REST	0.99	0.24	2.2	2.2
36-TLAND	0.99	0.24	2.2	2.2
37-TAIR	0.99	0.24	2.2	2.2
38-STORAGE	0.99	0.24	2.2	2.2
39-POST	0.99	0.24	2.2	2.2
40-FINAN	0.99	0.24	2.2	2.2
41-RESTATE	0.99	0.24	2.2	2.2
42-RENTAL	0.99	0.24	2.2	2.2
43-OTHSER	0.99	0.24	2.2	2.2
44-TELCOM	0.99	0.24	2.2	2.2
45-PUBADM	0.99	0.24	2.2	2.2
46-EDUC	0.99	0.24	2.2	2.2
47-HEALTH	0.99	0.24	2.2	2.2
48-ARTCULT	0.99	0.24	2.2	2.2

## Appendix C: Aggregated SAM for Bhutan (2017)

Million Nu

	L	K	H	FIRM	TOUR	GVT	TD	TM	TI	ROW	J	I	MARGIN	INV	VSTK	TOTAL
L										134	70 739					70 872
K											88 828					88 828
H	68 419			14 164		474				6 608						89 665
FIRM		64 888				461				2 234						67 582
TOUR										11 762						11 762
GVT		2 414		2 421	1 397		11 433	5 828	2 259	3 485	1 100					30 338
TD			1 342	10 091												11 433
TM												5 828				5 828
TI												2 259				2 259
ROW	2 453		1 072	11 228		2 341						81 574				98 669
J												263 920				263 920
I			80 230		10 364	30 688				37 635	103 253		23 200	91 573	1 522	378 465
MARGIN												23 200				23 200
INV		21 526	7 021	29 678		-3 626				36 812						91 410
VSTK												1 685		-163		1 522
<b>TOTAL</b>	<b>70 872</b>	<b>88 828</b>	<b>89 665</b>	<b>67 582</b>	<b>11 762</b>	<b>30 338</b>	<b>11 433</b>	<b>5 828</b>	<b>2 259</b>	<b>98 669</b>	<b>263 920</b>	<b>378 465</b>	<b>23 200</b>	<b>91 410</b>	<b>1 522</b>	

## Appendix D: Correspondence between variables and the SAM

	L	K	H	FIRM	TOUR	GVT	TD	TM	TI	ROW	J	I	MARGIN	INV	VSTK	TOTAL
L										$W^W \sum L S_{h,l} W$	$W_l L D_{l,j}$					$\sum W_{l,j} L D_{l,j} + Y L R O W_l$
K											$R_j K D_j$					$\sum R_j K D_j$
H	$Y H L_h$			$T R_{h,firm}$		$T R_{h,gvt}$				$T R_{h,row}$						$Y H_h$
FIRM		$Y F K$				$T R_{firm,gvt}$				$T R_{firm,row}$						$Y F$
TOUR										$T R_{tour,row}$						$Y T$
GVT		$Y G R$		$T R_{gvt,firm}$	$S D F$		$T D H T + T D F$	$T I M T$	$T I C T + T I X T$	$T R_{gvt,row}$	$T I P_j$					$Y G$
TD			$T D H_h$	$T D F$												$T D H T + T D F$
TM												$T I M_i$				$T I M T$
TI												$T I C_i$				$T I C T + T I X T$
ROW	$W_l L S_l^{ROW}$			$T R_{row,h}$	$T R_{row,firm}$		$T R_{row,gvt}$			$e P W E_i E X_i$		$e P W M_i I M_i$				$Y R O W$
J												$P D_i D D_i$				$P P_j X S T_j$
I			$P C_i C_{i,h}$		$P C_i C T_i$	$P C_i C G_i$					$P C_i D I_{i,j}$		$P C_i M R G N_i$	$P C_i I N V_i$	$P C_i V S T K_i^{IN}$	$P C_i Q_i$
MARGIN												$P C_{ij} t m r g_{ij,i} D D_i + P C_{ij} t m r g_{ij,i} I M_i$				$\sum P C_{ij} M R G N_{ij}$
INV		$D E P$	$S H_h$	$S F$		$S G$				$S R O W$						$I T$
VSTK												$P_i V S T K_i^{OUT}$		$P C_i V S T K_i^{IN} - P_i V S T K_i^{OUT}$		$\sum P C_i V S T K_i^{IN}$
TOTAL	$Y H L_h + W_l L S_l^{ROW}$	$\sum R_j K D_j$	$Y H_h$	$Y F$	$Y T$	$Y G$	$T D H T + T D F$	$T I M T$	$T I C T + T I X T$	$Y R O W$	$P P_j X S T_j$	$P C_i Q_i$	$\sum P C_i M R G N_i$	$I T$	$\sum P C_i V S T K_i^{IN}$	