Country-Specific Framework for Environmental Policy Analysis (CSAVE): Assessing International Financing for Climate Change Adaptation in Bangladesh

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Country-specific framework for environmental policy analysis (CSAVE) is a single-region computable general equilibrium (CGE) model with input-output table and trade activities calibrated based on Global Trade Analysis Project database. The goal of our work is to offer a concise scheme for analyzing policy impacts on a domestic economy, without the need of using a large-scale global CGE, which may be time consuming to run or is prone to encounter numerical challenges. Another advantage of using CSAVE is the ability to model the nominal exchange rate, a key variable typically not represented in global models. Two modeling exercises using CSAVE are provided: 1) we study implications on the domestic economy of Bangladesh when it receives foreign transfers via climate finance. The finding reveals that besides welfare gain, Dutch disease can be a potential side effect of receiving foreign transfers; 2) based on existing research on global warming and how the higher temperature could reduce crop land and labor productivities, we explore the economic impact of climate change on Bangladesh. We find that the present value for the 2020–2050 welfare loss due to climate change is around 89.8 billion USD, and the annual foreign transfers up to 2050 starting from 2026 in offsetting the loss is approximately 2.8 billion USD.

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1. Introduction

As global warming steadily progresses, climate change-induced impacts are threatening human life and causing socio-economic damage worldwide (IPCC, 2023). Developing and financially challenged countries are especially vulnerable to this trend due to their limited resources and low adaptive capacity. Therefore, it is critical to develop approaches to evaluate the climate impacts on the economy and options for mitigation and adaptation, in order to inform sound strategies to protect the economies.

Global integrated assessment models (IAMs) and computable general equilibrium (CGE) models (as a part of IAMs or in a standalone mode) with multiple regions and multiple economic sectors have been widely used for climate and environmental policy analyses (IPCC, 2023). These models are indispensable in analyzing policies and impacts with worldwide coverage and transboundary nature. However, applying them to a detailed analysis of a particular country, especially to those not among the world major economies, is often challenging due to model resolutions. When multi-region models are applied to study numerous economic sectors, technologies, or production factors, solving these models can quickly become rather cumbersome, and they sometimes face potential issues with numerical challenges and data availability.

In this study, we develop a country-specific modeling tool, which is derived based on GTAPinGAMS (Rutherford, 1998). It also benefits from applying the Global Trade Analysis Project (GTAP) database (Aguiar et al., 2022; Chepeliev, 2023) and an approach for the dynamic structure from a large energy-economic model (Chen et al., 2022). Our framework, called the country-specific framework for environmental policy analysis (CSAVE), provides the flexibility of focusing on a particular country of interest in the GTAP database. It also offers the option in pursuing a higher sectoral resolution without substantially increasing the levels of efficiency penalty or numerical challenge.

The goal of our effort is to offer a succinct scheme for analyzing energy, climate, and environmental policy impacts on domestic economy by applying a country-level CGE model with a single region setting. Our country-level framework allows a detailed representation of the evolution of an economy under different scenarios of economic development and policy. With a single-country setting, the representation of international trade between the domestic economy and the rest of the world is particularly important. For trade-related elasticities, we use an approach developed by Schreiber et al. (2024) to derive them from the simulated trade response to changes in prices of imports and exports. An important aspect of our country-level framework is an explicit representation of exchange rate dynamics under different trade closure settings. Global multi-region models, on the contrary, are typically formulated in the same currency for all regions (e.g., US dollars) and therefore the exchange rate is usually not represented.

To test the CSAVE framework, we apply it to the issue of international climate financing. We focus on Bangladesh as one of most vulnerable countries to climate change (Bangladesh NAP, 2022). We represent the impacts of climate change on crop land and labor productivities based on Reilly et al. (2007) and Hsiang (2010), and use the temperature projection for Bangladesh from Choi et al. (2021) to derive the productivity impacts and welfare loss. We then assess the implication of climate financing to address climate change impacts. We calculate the foreign transfers needed to compensate Bangladesh's welfare loss, and find that the aggregate consumption in Bangladesh increases with the amount of transfer, but over time non-tradable sectors expand while tradable sectors shrink, i.e., the economy shows the symptoms of Dutch disease.

We also explore the impacts of different designs and levels of foreign transfers on the structure of the domestic economy, and consider scenarios when transfers are received by either a representative agent, or affected agricultural sectors, or when transfers are dedicated to subsidizing carbon-free power generation. Our findings for Bangladesh may also shed light on understanding the potential impacts of other developing countries that are exploring the opportunity of international climate financing.

The rest of the study is organized as follows: Section 2 provides settings and structure of CSAVE, Section 3 offers background information of Bangladesh's economy and how crop land and labor productivity impacts are quantified, Section 4 presents simulation results for the welfare loss of Bangladesh due to climate change, and foreign transfers needed to compensate the loss. Section 5 provides conclusions and future research directions.

2. Model

2.1 Framework

CSAVE is a single-region recursive dynamic computable general equilibrium (CGE) model interacting with the rest of the world through international trade. The model utilizes the subroutine of GTAPinGAMS to produce the desired sectoral aggregation using the GTAP-power database (Chepeliev, 2023). The input-output table of the focused region is extracted from the aggregated dataset. In CSAVE, activities of various agents and their interactions are summarized by: 1) zero-profit conditions; 2) market-clearing conditions; and 3) income-balance conditions. For a producer, the economic activity is output, and for a household, the activity is utility. A zero-profit condition formulated as a Mixed Complementarity Problem (MCP) is:

$$MC - MR \geq 0; Q \geq 0\,; [MC - MR\,] \cdot Q = 0 \tag{1}$$

For a production activity, if the equilibrium output $Q > 0$, the first-order condition requires that the marginal cost equals the marginal revenue ($MC = MR$). Alternatively, if $MC > MR$ in equilibrium, $Q = 0$ as there is no incentive to produce. Finally, $MC < MR$ does not constitute an equilibrium since in that state it is profitable to increase the output Q until $MC = MR$. Other activities such as imports, exports, investment, and commodity aggregation have their own zero-profit conditions.

For each market-clearing condition, the price level is determined based on demand and supply. The market-clearing condition in MCP format can be written as:

$$S \geq D; P \geq 0\,; [S - D\,] \cdot P = 0 \tag{2}$$

The condition states that for each market, if there is a positive equilibrium price P, the price will make supply and demand equal ($S = D$). If $S > D$ in equilibrium, $P = 0$ due to the excess supply. Similarly, $S < D$ is not an equilibrium because in that case, suppliers are able to increase the price until the market is cleared.

The income-balance condition specifies the income supporting the household expenditure and savings. For consistency, the condition is expressed in MCP format as:

$$E \geq I; E \geq 0\,; [E - I\,] \cdot E = 0 \tag{3}$$

In Condition (3), E represents expenditure plus savings, and so the condition states that any positive expenditure plus savings equals the income I. In the model, the price of utility is chosen as the numeraire of the model, and all other prices are measured relative to it.

2.2 Social Accounting Matrix

The core of CSAVE is formulated in MPSGE (Rutherford, 1999) and the rest is written in GAMS (Bussieck and Meeraus, 2004). The model structure is best described by the social accounting matrix (SAM) in a "micro-consistent matrix" format (Figure 1), where each row of SAM is associated with a market-clearing condition of a commodity or service (Condition 2), and each column corresponds to a zero-profit condition of an activity (Condition 1), except for the last column, which represents the income-balance condition of the economy (Condition 3). Cells in blue denote output of each activity, supply of each market, or endowment of the representative agent (those in the rightmost column); Cells in light orange are input of each activity, demand for the commodity of each market, or aggregate consumption of the representative agent (those in the rightmost column). Notations for elements in SAM are explained in Tables 1–5, and Table 6 presents tax revenue components of the income-balance condition, which is handled automatically in the background by MPSGE.

For instance, for a non-electricity sector j (see the column "$Y_j|not\ elec$" in Figure 1) without using fixed factors (land and natural resources), when a positive output $vom0_j$ is produced in the base year, it would require the use of primary factor $vfm0_{f,j}$ and the intermediate input $vafm0_{i,j}$. The output and input values of the production activity are shown in (4) and (5), respectively:

$$P_j \cdot (1 - rto0_j) \cdot vom0_j \tag{4}$$

$$\sum_{f|mf} PP_f \cdot (1 + rtf0_{f,j}) \cdot vfm0_{f,j} + \sum_i PAC_i \cdot (1 + rtfa0_{i,j}) \cdot vafm0_{i,j} \tag{5}$$

The accounting identity (4) = (5) corresponds to a zero-profit condition with a positive output. Also taking the non-electricity sector j as an example, the market for the domestic output (the row labeled by P_j) is formed by: 1) the supply of the domestic output $vom0_j$, 2) the domestic demand of that output $vdfms_j$, which is the domestic component of the Armington good j, and 3) the foreign demand of that output $e0_j$, which is just the exports of j. The positive output of j implies a positive price of j (i.e., $P_j > 0$) in this market, which has the following equilibrium condition:

$$vom0_j = vdfms_j + e0_j \quad (6)$$

Finally, the column denoted by "RA" corresponds to an income balance condition of the representative agent (consumer), with the value of total expenditure (savings included) being:

$$PU \cdot vum0 \quad (7)$$

The value of the endowment is the sum of the following terms

$$\sum_{mf} PP_{mf} \cdot evfm0_{mf} \quad \text{(Labor and capital endowments)} \quad (8)$$

$$\sum_{sf} \sum_i PF_{sf,j} \cdot vfm0_{sf,i} \quad \text{(Non-power sector land \& natural resources)} \quad (9)$$

$$\sum_{sf} \sum_{i\_} PF_{\_sf,j} \cdot vfm0_{\_sf,i\_} \quad \text{(Similar to (9) but for power subsectors)} \quad (10)$$

$$-\sum_i PAC_i \cdot vafm0_{i,\text{"g"}} \quad \text{(Government expenditure)} \quad (11)$$

$$-\sum_i PESTAR_i \cdot e0_i \quad \text{(Exports)} \quad (12)$$

$$\sum_i PMSTAR_i \cdot m0_i \quad \text{(Imports)} \quad (13)$$

$$sum\_tax \quad \text{(Sum of tax revenue. See Table 6 for details)} \quad (14)$$

The income-balance condition is the following identity, which states that the consumer's savings included total expenditure equals the value of the endowments he owns:

$$(7) = \sum_{n=8}^{14} (n) \quad (15)$$

	Y (j) | not elec	Y (j) | elec	M(i)	A(i)	AC(i,g)	U	Z	E(i)	Y_ (j_)	Y__ (j_) | nfsl	Y___	INV	RA
P(j)	vom0(j)-e0(j) *rto0(j)*	vom0(j)		vdfms(i)									
PE(j)	e0(j) *rto0(j)*	e0(j)						e0(i) *-rtxse(i)*					
PM(i)			vim0(i)	vifms(i)									
PP(f) | mf	vfm0(f,j) *rtf0(f,j)*								vfm0_(f,j_) *rtf0_(f,j_)*				evfm0(mf)
PF(f,j) | sf	vfm0(f,j) *rtf0(f,j)*												vfm0(sf,i)
PF_(f,j_) | sf									vfm0_(f,j_) *rtf0_(f,j_)*				vfm0_(sf,j_)
PA(i)				vafms(i)	vafm0(i,g) *ctaxr(i)*								
PAC(i)	vafm0(i,j) *rtfa0(i,j)*				vafm0(i,g)		vafm0(i,"c") *rtfa0(i,"c")*		vafm0_(i,j_) *rtfa0_(i,j_)*			vafm0(i,"I") *rtfa0(i,"i")*	-vafm0(i,"g")
PU						vum0							vum0
PZ						vom0("c")	vom0("c")						
PESTAR(i)								e0(i)					-e0(i)
PMSTAR(i)			m0(i) *rtms0(i)*										m0(i)
P_(j_)		vom0_(j_)							vom0_(j_) *rto0_(j_)*	vom0_(j_)	vom0_(j_)		
P__		vom0_dn								vom0_(j_)	vom0_f		
PINV						vafmi						vafmi	
	tax_Y(j)				tax_AC(i,g)		tax_Z	tax_E(i)	tax_Y_(j_)			tax_INV	tax revenue

Figure 1. SAM structure of CSAVE

Table 1. Price indices

Price notation	Definition
P(i)	Domestic output price index
PM(i)	Import price index
PP(f)	Labor or capital rent index
PE(i)	Price index for tax & subsidy excluded exports in domestic currency
PW(i)	Foreign price index for tariff excluded imports of domestic economy
PF(f, i)	Land or natural resource rent index
PF_(f, i_)	Power sector natural resource rent index
PA(i)	Armington good price index
PAC(i)	Carbon-penalty-included PA
PU	Price index for utility (savings included)
PZ	Price index for aggregate consumption
PESTAR(i)	Price index for tax & subsidy included exports in domestic currency
PMSTAR(i)	Price index for tariff excluded imports
P_(i_)	Power subsector domestic output price index
P__	Domestic output price index for dispatchable generation
PINV	Price index for investment
ER	Nominal exchange rate (Price index of foreign currency)

Table 2. Activities

Activity notation	Definition
Y(i)	Supply (domestic production) index
M(i)	Imports index
A(i)	Armington good/service index
AC(i, g)	Index for Armington good/service with carbon penalty
U	Utility index
Z	Aggregate consumption index
E(i)	Exports index
Y_(i_)	Index for supply (domestic production) of a power subsector
Y__(i_)	Index for homogeneous transformation for power subsectors: nuclear, hydro and others
Y___	Index for fossil generation aggregation
INV	Index for investment

Table 3. Sets

Set notation	Definition
g	Goods + private consumption (“c”), government expenditure (“g”), & investment (“i”)
i	Goods/sectors: subset of g
j	Alias of i: subset of g
f	Primary factors
mf	Mobile primary factors (labor & capital)
sf	Sector-specific primary factors (land & natural resources)
i_	Power subsectors
j_	Alias of i_

Table 4. Parameters with base year values

Parameter	Definition
vom0(g)	Total supply (domestic output) at market prices
vom0_(j_)	Power subsectors’ total supply (domestic output) at market prices
vfm0(f, j)	Endowments (factors) – firms’ purchases at market prices
vfm0_(f, j_)	Endowments (factors) – power subsectors’ purchases at market prices
vdfm0(i, g)	g’s domestic purchase of i (tax excluded)
vdfms(i)	Sum of vdfm0(i, g) over g
vifm0(i, g)	g’s purchase of imported i (tax excluded)
vifms(i)	Sum of vifm0(i, g) over g
vafm0(i, g)	Armington good i used by g (tax excluded); = vdfm0(i, g)+vifm0(i, g)
vafm0_(i, j_)	Armington good i used by power subsectors j_ (tax excluded)
vom0_(i_)	Power subsector total supply (domestic output) at market prices
vom0_d	Aggregate dispatchable generations
vim0(i)	Tariff-included imports
m0(i)	Tariff-excluded & importing-transport-service-included imports
vum0	Utility level
vafmi	Aggregate investment
e0(i)	Subsidy-excluded & exporting-transport-service-included exports
evfm0(mf)	Non-fixed factor endowment (labor; capital) at market prices
vfm0(sf,i)	Fixed factor endowment (land; natural resources) at market prices
vfm0_(sf,i_)	Power subsectors’ fixed factor endowment (land; natural resources) at market prices

Table 5. Base year tax or subsidy rates

Tax/subsidy rate	Definition
rto0(j)	Tax/subsidy rate on output
rto0_(j_)	Tax/subsidy rate on output (of power subsector j_)
rtf0(f, j)	Tax/subsidy rate on primary factor
rtf0_(f, j_)	Tax/subsidy rate on primary factor (of power subsector j_)
rtfa0(i, g)	Base year effective tax/subsidy rate on Armington good i use by g
rtfa0_(i, j_)	Base year effective tax/subsidy rate on Armington good i use by power subsector j_
rtms0(i)	Tax/subsidy rate on imports
rtxse0(i)	Export incentive rate in the base year imposed by home country
rtxse(i)	Export incentive rate imposed by home country
ctaxr(i)*	Carbon tax rate

* The base year carbon tax rate $\mathrm{ctaxr(i)} = 0$.

Table 6. Base year tax revenues

Revenue	Definition
tax_Y(j)	$\mathrm{rto0(j) \cdot vom0(j) + \sum_f rtf0(f,j) \cdot vfm0(f,j) + \sum_i vafm0(i,j) \cdot rtfa0(i,j)}$
tax_AC(i, g)*	$\mathrm{vafm0(i,g) \cdot ctaxr(i)}$
tax_Z	$\mathrm{\sum_i vafm0(i,"c") \cdot rtfa0(i,"c")}$
tax_E(i)	$\mathrm{e0(i) \cdot rtxse(i)}$
tax_Y(j_)	$\mathrm{rto0\_(j\_) \cdot vom0\_(j\_) + \sum_f rtf0\_(f,j\_) \cdot vfm0\_(f,j\_) + \sum_i vafm0\_(i,j\_) \cdot rtfa0\_(i,j\_)}$
tax_INV	$\mathrm{\sum_i vafm0(i,"i") \cdot rtfa0(i,"i")}$
sum_tax	$\mathrm{\sum_j tax\_Y(j) + \sum_i \sum_g tax\_AC(i,g) + tax_Z + \sum_i tax\_E(i) + \sum_{j\_} tax\_Y(j\_) + tax\_INV}$

* The base year carbon tax rate $\mathrm{ctaxr(i)} = 0$, and so in base year $\mathrm{tax\_AC(i,g)} = 0$.

2.3 International trade

CSAVE considers the case where each commodity (or service) is differentiated by country of origin, following Dervis et al. (1982). Therefore, for a given commodity i, the domestic economy may face a negatively sloped export demand and a positively sloped import supply curves. To elaborate the setting, let us denote PWE_i as the foreign price index of commodity i exported from the domestic economy. Following notations defined in Table 1 and Table 5, PWE_i can be expressed as:

$$PWE_i = PE_i \cdot (1 + rtxse_i)/ER \quad (16)$$

Equation (16) reveals that imposing export subsidy (setting $rtxse_i < 0$) and devaluation of domestic currency (ER increases) will make the export of i more competitive. Let us denote the elasticity of export demand by α_i:

$$\alpha_i = dlnE_i/dlnPWE_i\ ;\ \alpha_i \leq 0 \quad (17)$$

PWE_i in Equation (17) is the price faced by foreign consumers (not represented explicitly in the single country framework). The export demand for commodity i, denoted by E_i, can be derived accordingly as:

$$E_i = E_i^0 \cdot \left[\frac{(1+rtxse_i^0)\cdot ER}{(1+rtxse_i)\cdot PE_i}\right]^{-\alpha_i} \quad (18)$$

Therefore, E_i increases if there is: 1) a devaluation in domestic currency, 2) an increase in export subsidy ($rtxse_i < 0$ but $|rtxse_i|$ increases), and 3) a decrease in PE_i (domestic price index of E_i excluding the export subsidy). Equation (18) also shows that when $\alpha_i \to -\infty$, the home country is "small" for the export of i since other things being equal, even a tiny increase in PE_i beyond the base year level will lose all of the exports. On the other hand, when $\alpha_i \to 0$, the home country is "large" for exporting i since exports are insensitive to PE_i.

The import supply M_i can be derived from the elasticity of import supply β_i:

$$\beta_i = d\ ln\, M_i\ /d\ ln\, PW_i\ ; \beta_i \geq 0 \quad (19)$$

PW_i in Equation (19) is the pre-tariff foreign price index of commodity i imported by the domestic economy (Table 1), and it is the price perceived by foreign suppliers (not represented explicitly in the single country framework). The import supply M_i is therefore:

$$M_i = M_i^0 \cdot PW_i^{\beta_i} = M_i^0\ \cdot \left(\frac{PMSTAR_i}{ER}\right)^{\beta_i} \quad (20)$$

In Equation (20), import supply M_i will go up when PW_i increases, and for a given $PMSTAR_i$, the pre-tariff domestic price index of imported commodity i, an appreciation in domestic currency (i.e., ER decreases) will increase PW_i and consequently raises M_i for any $\beta_i > 0$. In addition, when $\beta_i \to \infty$, the domestic economy is "small" as an importer of i since if it is willing to pay a slightly higher price than the equilibrium level, there will be a huge increase in import supply relative to the original import level M_0. Alternatively, when β_i is small, the domestic economy is "large" because even it is willing to pay a significant premium over the equilibrium price, the import supply will not increase much relative to the original import level M_0. In the extreme case $\beta_i \to 0$, the import supply remains at M_0 regardless of any premium paid.

To parameterize α_i and β_i, we follow Schreiber et al. (2024) and build a 2-region CGE that has the domestic economy and the rest of the world, with structure and parameterization mirroring those in CSAVE, except for settings of region and international trade. The goal is to derive α_i and β_i by shocking the relevant price variables, as illustrated in Equations (21) and (22):

$$\alpha_i = \frac{\%\ change\ in\ foreign\ demand\ for\ i\ exported\ by\ the\ domestic\ economy}{\%\ change\ in\ PE_i} \tag{21}$$

$$\beta_i = \frac{\%\ change\ in\ foreign\ supply\ of\ i\ imported\ by\ the\ domestic\ economy}{\%\ change\ in\ PW_i} \tag{22}$$

We find that in general, Bangladesh is a price taker of various commodities in international trade, especially in terms of imports (Table 7). Note that when deriving elasticities, for some sectors there are no exports or imports in the base year data, and in that case the export demand or import supply elasticities cannot be simulated. In the modeling exercise, each missing elasticity will be assigned the value of zero. For numerical reasons, import supply elasticities that are higher than 100 will be represented by the values of 100.

For the export market of commodity i, besides the export demand (Equation (18)), the export supply of each commodity i is determined by the zero-profit condition (Condition (1)) for a joint production technology that differentiates and distributes the producer's output between export and domestic sales for profit maximization.

Likewise, for the import market of commodity i, in addition to the import supply (Equation (20)), the import demand is the derived demand of the representative consumer's utility maximization problem—the level of import demand is dependent on the zero-profit condition for the "production" of Armington good, which aggregates imported and domestic products, and the Armington good demand is in turn determined by the zero-profit condition for the "production" of utility. The import and export markets as well as trade balance closure setting will determine

ER, the price of foreign exchange (i.e., nominal exchange rate), which will be discussed in Section 2.5.

Table 7. Simulated export demand and import supply elasticities

sector	export demand	import supply
paddy rice	-9.6	>100
wheat	-	30.3
cereal grains nec	-	98.3
vegetables – fruit – nuts	-3.5	53.3
oil seeds	-5.1	89.3
sugar cane – sugar beet	-	-
plant-based fibers	-4.1	9.4
crops nec	-6.1	>100
bo horses	-	-
animal products nec	-2.6	>100
raw milk	-8.3	>100
wool – silk-worm cocoons	-	-
forestry	-4.6	>100
fishing	-2.4	>100
coal	-	>100
oil	-	>100
gas	-	-
bo meat products	-	>100
meat products	-10.8	>100
vegetable oils and fats	-7.4	32.2
dairy products	-	>100
processed rice	-5.8	31.9
sugar	-6.7	33.9
food products nec	-4.5	>100
beverages and tobacco products	-2.4	>100
petroleum – coal products	-5.5	38.3
other industrial sectors	-0.4	2.1
electricity	-	77.9
service sectors – tradable	-3.3	>100
service sectors – non-tradable	-	-

2.4 Technology and preference

In CSAVE, constant elasticity of substitution (CES) functions (Arrow et al., 1961) are used to model the production technologies and utility. While the output of utility function is the welfare level (a.k.a. utility), the output for each production technology is a composite that includes domestic sales and exports—the distribution of them is modeled by a constant elasticity of transformation (CET) function (Powell and Gruen, 1968). To provide an example for a production technology with a CES input and CET output, let us consider a technology that uses two inputs—labor F_L and capital F_k— to produce domestic sales Q_D and exports Q_E. Using the calibrated share form (Rutherford, 1998) and normalizing prices and quantities at the calibration point to unity, the CES production function for the composite good Q is:

$$Q = \left(\sum_m \gamma_m F_m^{\rho}\right)^{\frac{1}{\rho}}; m = L, K \qquad (23)$$

where γ_m is the base year (i.e., the calibration point) cost share of the primary factor F_m ($m = L; K$), and ρ is the parameter that relates to the elasticity of substitution between the two primary factors, denoted by σ, in the following equation:

$$\sigma \equiv [\frac{d\left(\frac{F_l}{F_k}\right)}{\left(\frac{F_l}{F_k}\right)}]/[\frac{d\left(\frac{P_k}{P_l}\right)}{\left(\frac{P_k}{P_l}\right)}] = \frac{1}{1-\rho} \qquad (24)$$

In Equation (24), P_l and P_k are the rental prices for labor and capital, respectively. Let us denote the dual of the production function as $C(P_l, P_k, Q)$, which is the cost function for producing Q:

$$C = \left(\sum_m \gamma_m P_m^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \cdot Q \qquad (25)$$

A positive substitution elasticity holds if and only if $\rho < 1$. When $\rho \to 0$ the CES function becomes Cobb-Douglas. Other special cases include: 1) perfect substitution between inputs ($\rho \to 1$); and 2) Leontief, i.e., no substitution possibility between inputs ($\rho \to -\infty$).

On the output side, the composite good Q is transformed into Q_D and Q_E according to the CET function:

$$Q = \left(\sum_n \theta_n Q_n^{v}\right)^{\frac{1}{v}}; n = D, E \qquad (26)$$

where θ_n is the base year value share of commodity n ($n = D; E$) and v is the parameter that is associated with the elasticity of transformation τ between domestic sales and exports:

$$\tau \equiv [\frac{d\left(\frac{Q_E}{Q_D}\right)}{(\frac{Q_E}{Q_D})}]/[\frac{d\left(\frac{P_E}{P_D}\right)}{(\frac{P_E}{P_D})}] = \frac{1}{v-1} \tag{27}$$

In Equation (27), P_E and P_D are prices for exports and domestic sales, respectively. Let us denote the dual of the transformation function as $R(P_E, P_D, Q)$, which is the revenue function for a given level of composite Q:

$$R = (\sum_n \theta_n P_n^{\tau-1})^{\frac{1}{\tau-1}} \cdot Q \tag{28}$$

Likewise, a positive transformation elasticity holds if and only if $v > 1$. When $v \to 1$, there is a perfect transformation possibility between outputs, and when $v \to \infty$, there is no transformation possibility between outputs.

The optimal levels of exports and domestic sales are determined by their respective zero-profit conditions. Taking the level of exports as an example, the marginal cost for the production of exported good is:

$$MC_E \equiv \frac{\partial C}{\partial Q_E} = \frac{\partial C}{\partial Q} \cdot \frac{\partial Q}{\partial Q_E} \tag{29}$$

Based on Equations (25) and (26), we have:

$$\frac{\partial C}{\partial Q} = (\sum_m \gamma_m P_m^{1-\sigma})^{\frac{1}{1-\sigma}} \tag{30}$$

$$\frac{\partial Q}{\partial Q_E} = Q^{1-v} Q_E^{v-1} \tag{31}$$

Since $v = 1/\tau + 1$ (Equation 28), MC_E can be written as:

$$MC_E = (\sum_m \gamma_m P_m^{1-\sigma})^{\frac{1}{1-\sigma}} \cdot Q^{-1/\tau} Q_E^{1/\tau} \tag{32}$$

Therefore, the marginal cost for producing the exported good is an increasing function of its level Q_E, a decreasing function of composite Q, and an increasing function of the price for each input m. To determine Q_E, one can use the corresponding zero-profit condition (Condition (1)) based on Equation (32). The structures for a typical production technology and preference are demonstrated in Figures 2 and 3, respectively.

Besides, the power sector in CSAVE includes 9 subsectors (Figure 4). Following Gurgel et al. (2023), we make renewables (wind and solar) perfect substitutes to other forms of generation, while considering the value factor adjustment proposed by Mowers et al. (2023). The adjustment considers the observation that higher market shares of renewables in total electricity generation increase the "profit-adjusted levelized costs of electricity (PLCOE)" for renewables (Figure 4), i.e., the generation costs of renewables are higher as their market shares get larger. The cost function structure for power sector aggregation is also presented in Figure 4.

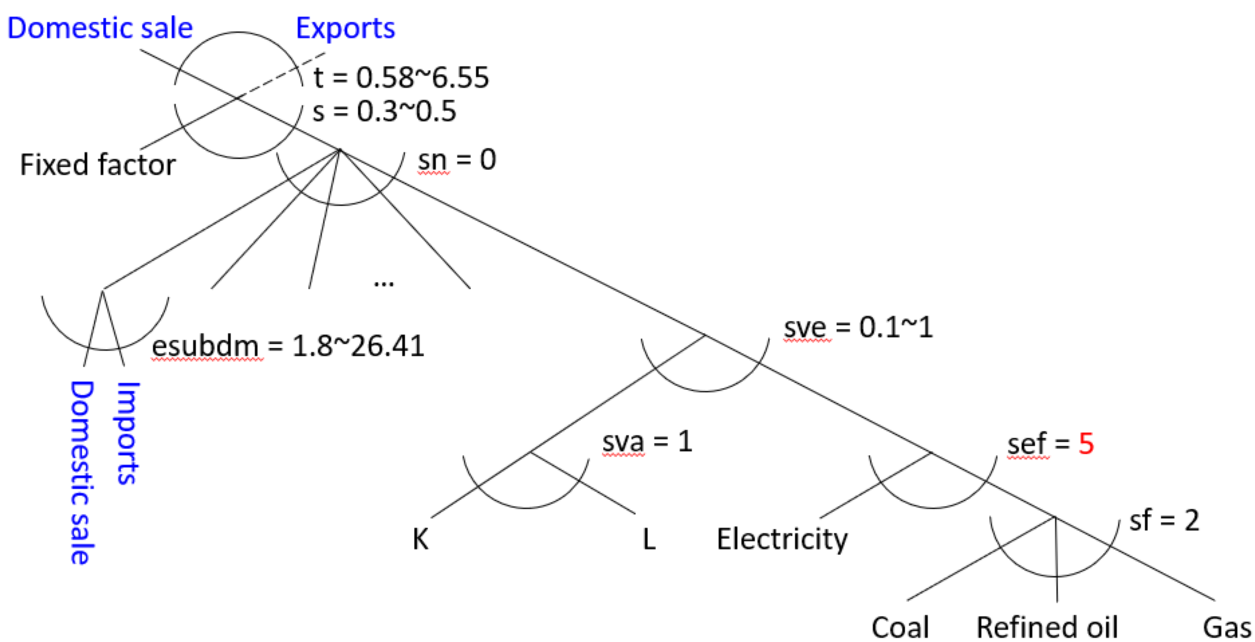


Figure 2. Cost function for a production sector

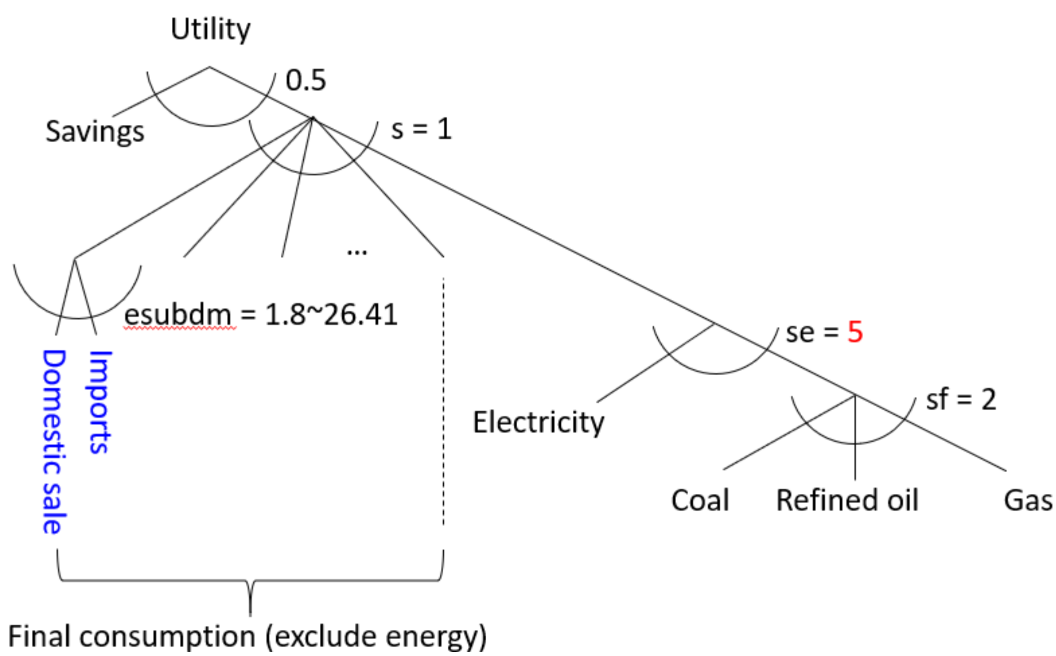


Figure 3. Expenditure function

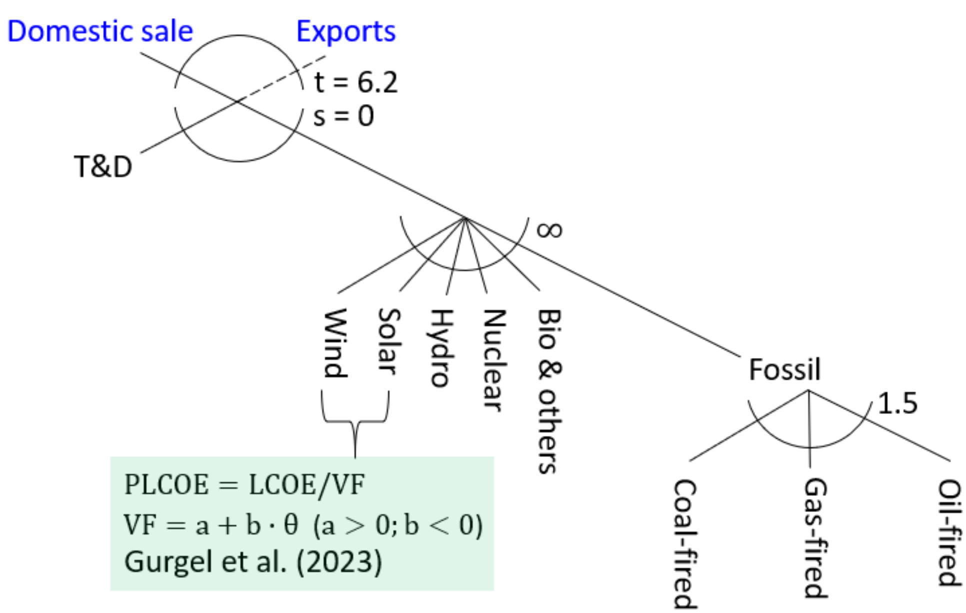


Figure 4. Cost function for power sector's aggregation

2.5 Model closures

Closures of a CGE model specify the rules for how markets are cleared or macro balances (receipts equal payments) are achieved (UNESCWA, 2020). Each closure involves a decision about what variable can be adjusted to reestablish an equilibrium after the model receives a shock (Cornerstone CGE, 2024). Key closures of CSAVE includes those for :1) labor market; 2) trade balance; 3) government expenditure; and 4) macroeconomics.

The labor market closure of our model considers the circumstance where the economy is in full employment—wage rate is flexible and can be adjusted upward or downward to equalize labor supply and demand. In our model, labor supply level is fixed within a given period. Therefore, the wage rate is fully determined by labor demand, which can be derived from producers' cost minimization problems using the Shephard's Lemma (Shephard, 1970).

CSAVE allows modelers to choose different settings for trade balance closure for comparison purposes or to better represent the country-specific characteristic. To illustrate this, let us denote the net capital outflow of the domestic economy by F, which is just the difference between the values of exports and imports, and denote the received foreign transfer by FTD:

$$F = FTD + \frac{1}{ER} \cdot \sum_i \frac{PE_i}{1+rtxse_i} \cdot E_i - \sum_i PW_i \cdot M_i \tag{34}$$

To model the flexible exchange rate setting, the net capital outflow is fixed within a given period, and can be either fixed or updated across periods. Throughout the study, we consider the flexible exchange rate setting where within a period, the net capital outflow remains constant, but over time it will be updated proportional to previous period's gross domestic product (GDP) level. Alternatively, when the nominal exchange rate is fixed, ER is constant and other prices in the international trade markets are adjusted to meet the relevant market clearing conditions, and the net capital outflow of Equation (34) becomes endogenous.

In CSAVE, the representative consumer allocates the income between consumption and savings to maximize his utility, and savings provides fund for investment, i.e., investment is driven by savings, i.e., the more the economy saves, the higher investment it achieves. The investment beyond the depreciation level eventually expands the production capacity of the following period. The setting constitutes the model's macroeconomics closure.

For the government expenditure closure, we assume the "quantities" of government purchases from various sectoral outputs are fixed within a given time period, i.e., $vafm0_{i,"g"}$ in Equation (11) remains a constant vector in that period. However, over time those quantities are updated proportional to the GDP of the economy. Besides, the standard setting of CSAVE assumes that tax revenues are recycled in a lump-sum fashion back to the representative consumer. Nevertheless, with some revisions, other settings can be incorporated into modeling exercises. We will provide some examples with different tax revenue recycling assumptions later.

2.6 Parameterization and calibration

The SAM of CSAVE comes from the input-output dataset presented in GTAP-power version 11 (Chepeliev, 2023). In the database, the input-output table for Bangladesh was contributed by the Bangladesh Planning Commission (Aguiar et al., 2022), and the Bangladesh data and those for other countries were adjusted and recompiled to ensure global consistencies in trade flows for the base year of 2017. The data are key inputs in parameterizing preference and various technologies in general (see Section 2.2 for details).

Another data required in calibrating technologies and preference are elasticities of substitution between inputs and elasticities of transformation between outputs (see Section 2.4 for details). These elasticities are mostly sourced from existing studies (Table 8), except for the elasticities of transformation between outputs for domestic sale and those for exports, which are often unavailable for existing research.

To overcome this, Lanz and Rutherford (2016) assumes that for each commodity type, the transformation elasticity is proportional to the substitution elasticity between imported good and the indigenous product sold domestically. We adopt the strategy and calibrate transformation elasticities $etadx$ such that they are half the levels for the corresponding substitution elasticities $esubdm$. The calibration ensures that CSAVE captures the average trend of Bangladesh's historical foreign exchange rate evolution (Figure 5). Besides, with lower transformation elasticities, it is harder for the domestic economy in diverting production resources to increase exports, which provide foreign exchange in supporting for the purchase of imports. In this case, there will be a higher extent of devaluation in domestic currency (Figure 5).

Another critical task for building CSAVE is calibrating the business-as-usual (BAU; no additional policies) growth path for GDP. In this study, the simulated BAU GDP growth for Bangladesh up to 2030 is calibrated to IMF World Economic Outlook (IMF, 2025). For years beyond 2030, the growth is assumed to decrease exponentially to 3% in 2050. To match the given GDP growth path, following Chen et al. (2022), for each period, the total factor productivity (TFP) of the economy is endogenously solved first. The solution for TFP is saved and used to parameterize the model for subsequent simulations, and it remains exogenous across scenarios. While the solved TFP path allows the model to reproduce the targeted GDP growth path under the BAU scenario, in general, the GDP growth as well as other economic variables will deviate from the BAU levels under a policy run.

Table 8 Substitution and transformation elasticities of CSAVE

	Notation	Value	Source
Substitution elasticity between			
fixed factor and other inputs (top nest)	esub	0.3-0.5	Cossa (2004)
aggregate consumption and savings (top nest)	esub	1	Rutherford (1998)
intermediate inputs	esubn	0.5	Hertel (1997)
primary factors (labor & capital)	esubva	1	Cossa (2004)
value-added and energy	esubve	0.4	Paltsev et al. (2005)
electricity and fossil fuels	esubef	1.5	Chen et al. (2022)
fossil fuels	esubf	1	Chen et al. (2022)
investment goods	esubi	1	Paltsev et al. (2005)
consumption goods	esubc	1	Rutherford (1998)
T&D and generation	esubet	0	Chen et al. (2022)
fossil fuel generation	esubfg	1.5	Chen et al. (2022)
imports and indigenous product sold domestically	esubdm	1.2-13.1	Chepeliev (2023)
Transformation elasticity between			
output for domestic sale and that for exports	etadx	0.6-6.6	Author's assumption

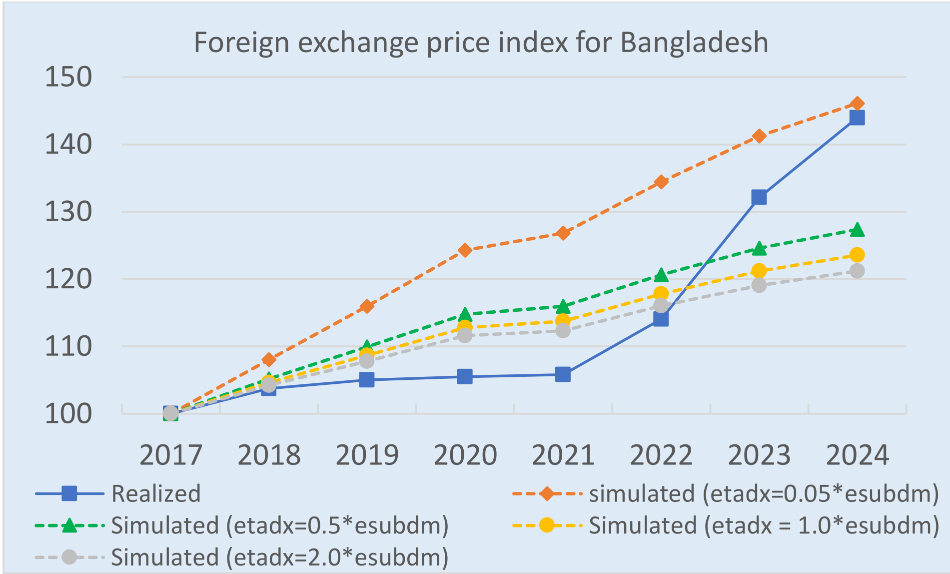


Figure 5. Foreign exchange price index under different transformation elasticity levels

3. Implications of receiving foreign transfers from climate finance

To alleviate the impact of climate change, during the 29th Conference of the Parties (COP29), the New Collective Quantified Goal on Climate Finance (NCQG) was agreed by almost 200 countries after yearslong preparations and negotiations. Under the climate finance agreement, by 2035, annual finance to developing countries is planned to scale up to 300 billion US dollars, and to 1.3 trillion US dollars when efforts from private sectors are counted (UNFCCC, 2024). Under the context, we use CSAVE to explore implications on Bangladesh's economy when it receives foreign transfers via the climate finance.

Foreign transfers supply the domestic economy extra resources at its disposal. As a result, the domestic welfare (i.e., aggregate consumption) is non-decreasing when foreign transfers increase. On the other hand, the capital influx may also change prices, outputs and resource allocations, which means while some sectors benefit, others may suffer.

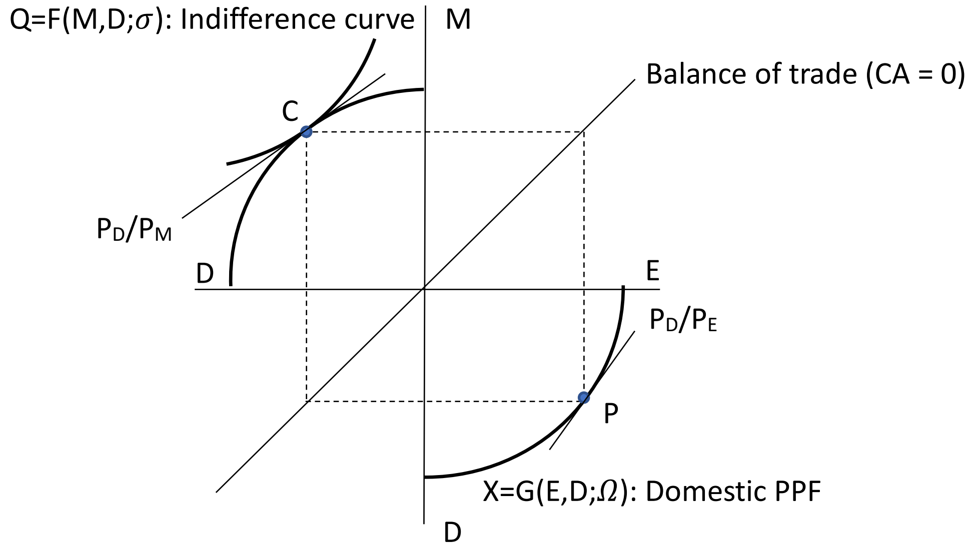
The 1-2-3 model developed by Devaragan et al. (1990) sheds light upon potential impacts of receiving foreign transfers. The one-country model has two sectors producing an export good E and a domestic good D, respectively, and it also has an import M. World prices for exports and imports are fixed following the small-country assumption. The representative consumer has a

CES preference over D and M with a substitution elasticity σ, and the representative producer has a CET production technology in producing D and E with a transformation elasticity Ω.

Devaragan et al. normalizes import and export prices to unity, and assumes initially there is no capital inflow. The production is determined by the relative price P_D/P_E tangent to the production possibility frontier (PPF) in the 4th quadrant (Figure 6a). The output D is supplied to the domestic market, and the export E determines how much import M the country can buy based on the balance of trade constraint. The combinations of these M and D form the consumption possibility frontier (CPF). The consumer chooses products on the CPF to maximize his utility under the relative price P_D/P_M (see the 2nd quadrant of Figure 6a). In equilibrium, the economy produces at point P and consumes at point C.

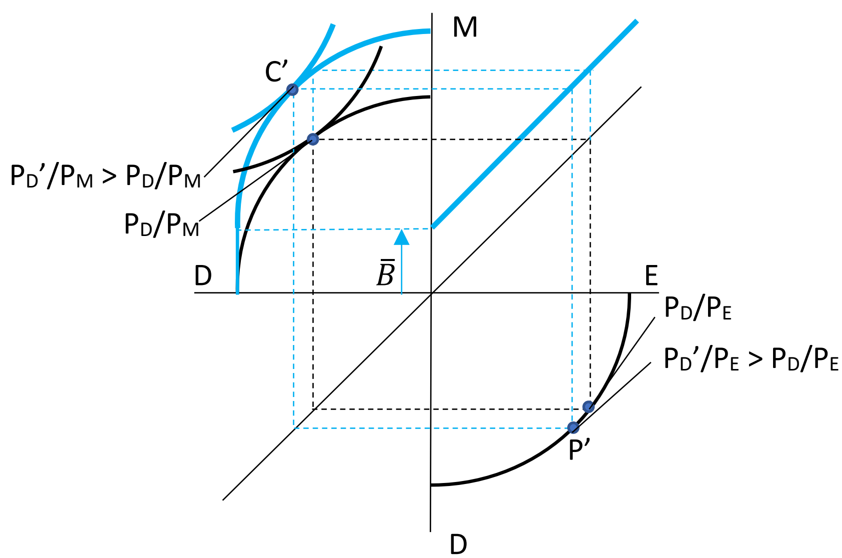
When the country receives a foreign transfer $\bar{B}$, the balance of trade line will shift upward by $\bar{B}$, and this in turn moves the CPF up also by $\bar{B}$. In the new equilibrium, the economy consumes at point C' and produces at point P' (Figure 6b). Consumption levels of M and D rise, and the price of domestic good P_D goes up, which leads to a real appreciation that favors the domestic good against exports, i.e., the economy would have a "Dutch disease."

While CSAVE parameterizations for α_i (elasticity of export demand) and β_i (elasticity of import supply) may not precisely agree with the small-country assumption used in the 1-2-3 model, as long as both imported and domestic goods are normal, receiving foreign transfers would increase the consumption of both commodities, and incentivizes the shift of production from exports to domestic sales, as Devaragan et al. predicts.



Source: Devaragan et al. (1990)

Figure 6a. The 1-2-3 model: baseline



Source: Devaragan et al. (1990)

Figure 6b. The 1-2-3 model: receiving a foreign transfer

To verify this, we first consider a scenario where the foreign climate finance given to Bangladesh goes to domestic consumers in a lump-sum fashion. The simulation shows that when the transfer increases (Figure 7), the aggregate consumption goes up since the sales of both domestic and imported goods rise (Figure 8; Figure 9).

At the same time, the average price for sales of domestic output goes up, and prices for imports and exports drop (Figure 10), consistent with the projection of increased P_D/P_M and P_D/P_E by the 1-2-3 model. The shift of the relative price is in favor of domestic goods and against exports, which is supported by the simulation for exports (Figure 11). In addition, our simulation also shows that the inflow of foreign transfer raises the overall supply of foreign exchange and therefore lowers the nominal exchange rate (Figure 12).

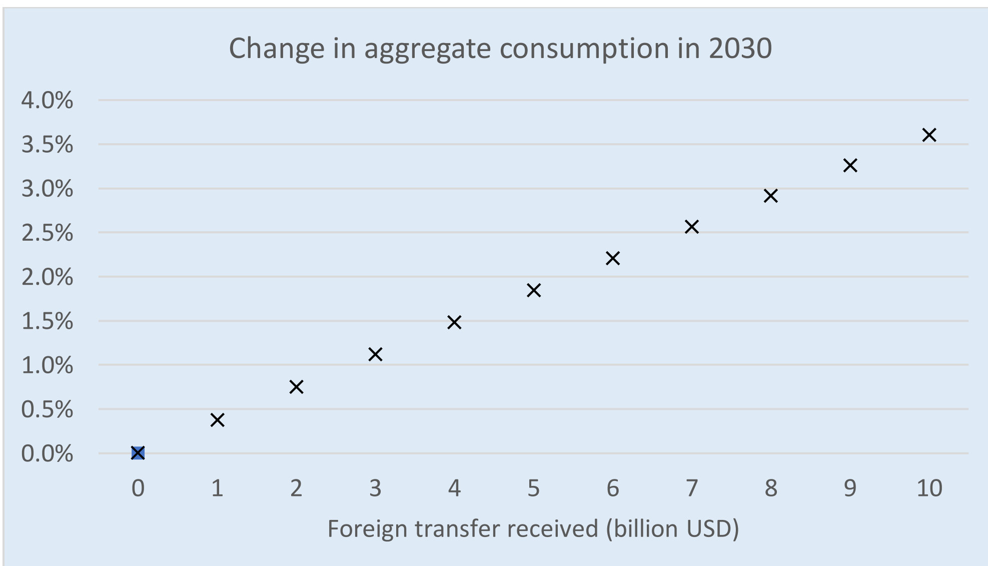


Figure 7. Change in aggregate consumption

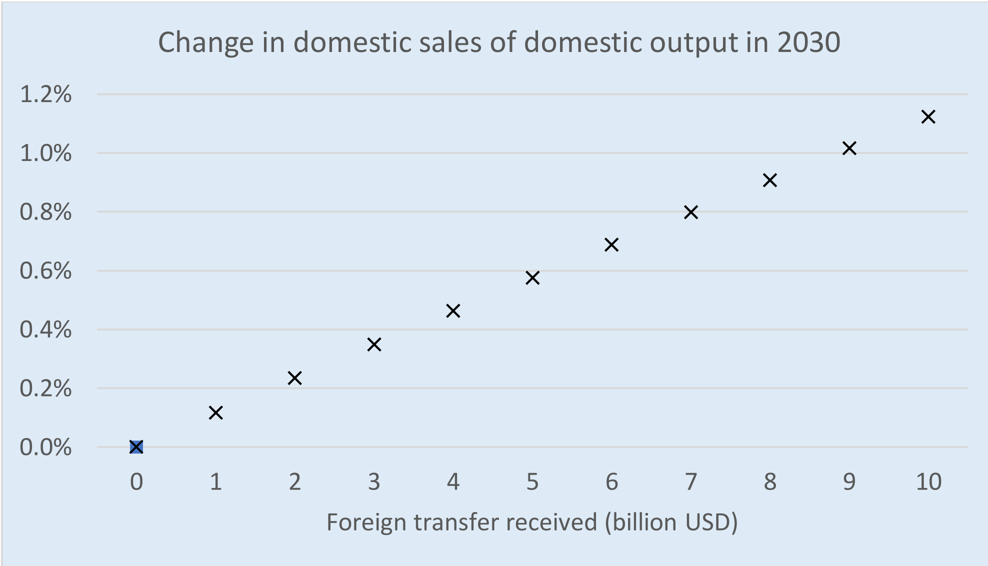


Figure 8. Change in domestic sales of domestic output

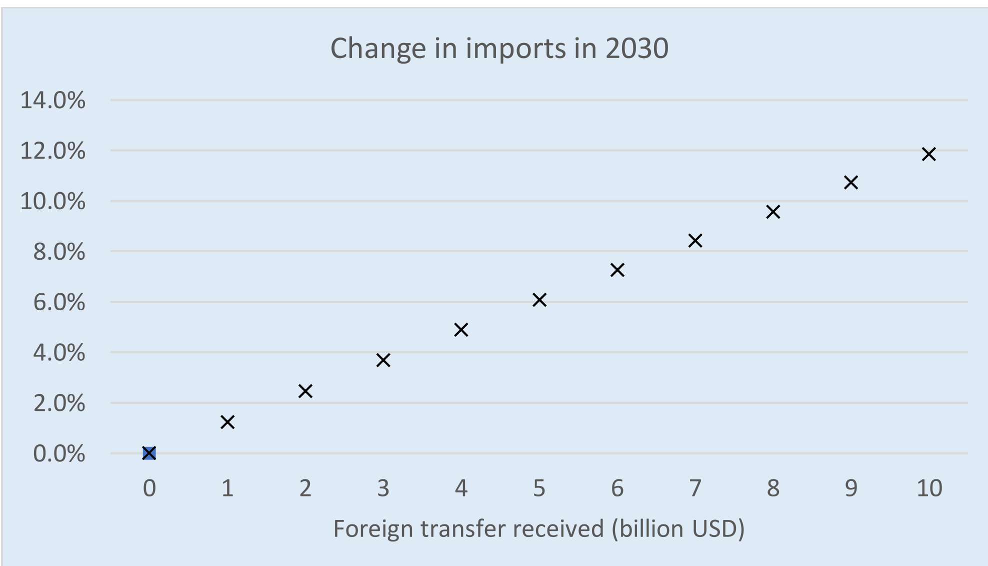


Figure 9. Change in imports

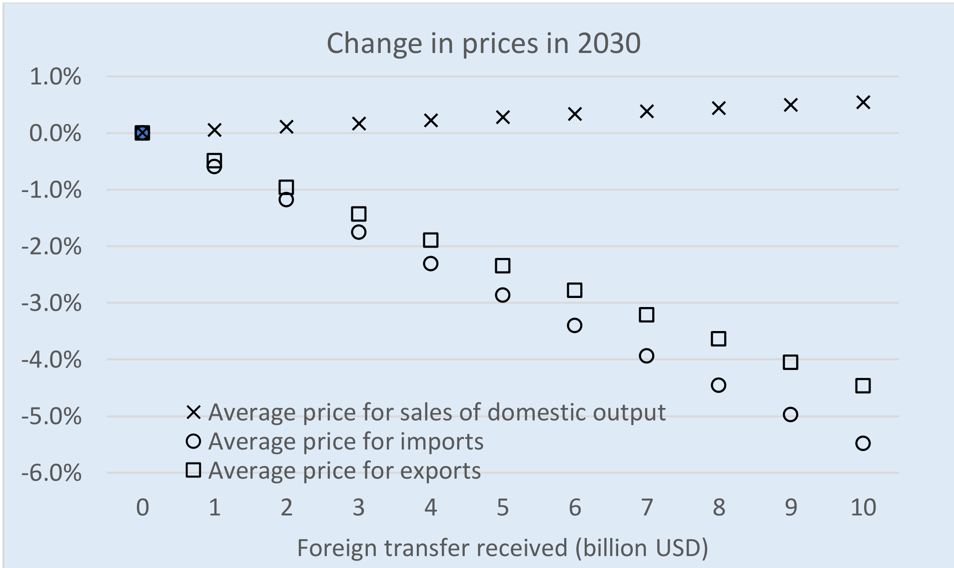


Figure 10. Change in prices

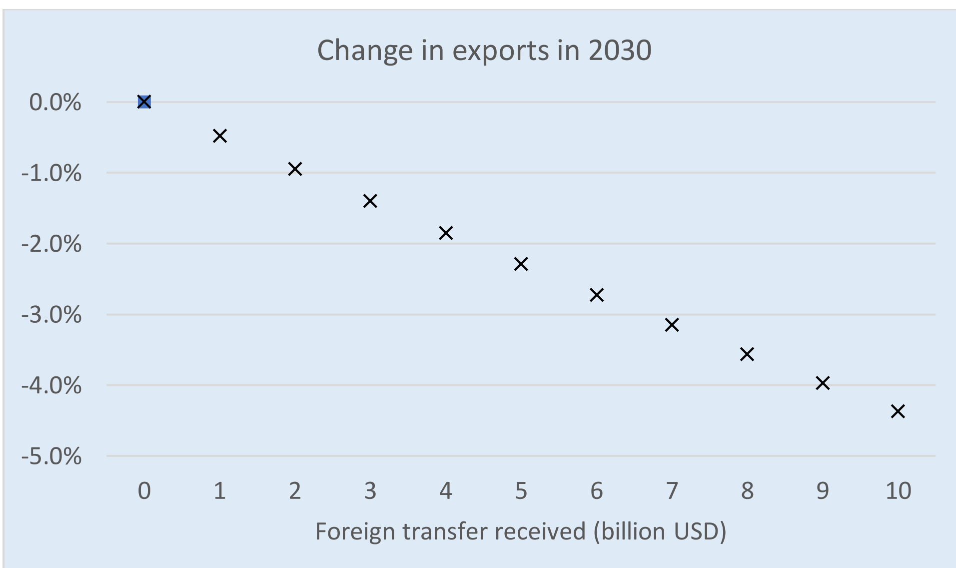


Figure 11. Change in exports

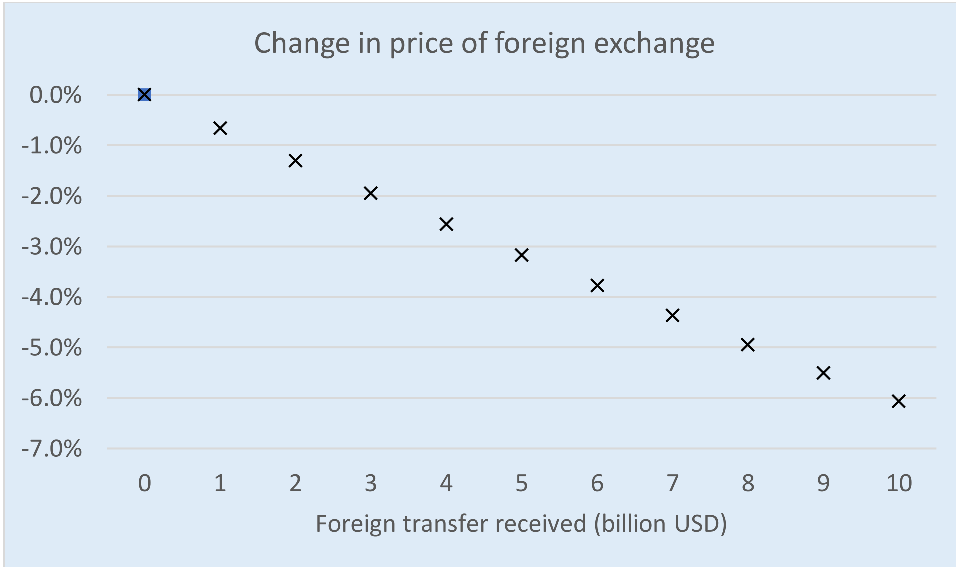


Figure 12. Change in price of foreign exchange

Instead of a lump-sum transfer to consumers, climate finance funds are usually required to be used in green development, such as subsidizing low-carbon energy supply technologies, in mitigating or compensating the loss due to impacts of global warming, such as the Loss and Damage Fund to support farmers in poorer countries that are suffering most from the climate crisis (World Economic Forum, 2024). As a result, we present another two scenarios, where climate transfers to Bangladesh are used in 1) subsidizing carbon-free power generation; and 2) subsidizing agricultural sectors, which are vulnerable to global warming.

For each of the two additional scenarios, the aggregate consumption goes up as foreign transfers rise, too, since the representative consumer is also the owner of primary factors (labor, capital, and natural resources) that are used in various production sectors. Subsidies to industrial sectors increase the representative consumer's income for consumption and decrease the relative prices of the subsidized commodities. With that, the increase in aggregate consumption is highest with the lump-sum transfer to household (Figure 13), since without restrictions on the usage of transfers, the allocation of primary factors among sectors is most efficient—it is determined purely by profit maximization without being affected by policies favoring some sectors and discriminating against others beforehand.

For these subsidy scenarios, the lower increase in aggregate consumption reflects the new equilibrium prices yield suboptimal resource allocations in welfare maximization, and changes in domestic sales of domestic outputs, imports, and exports are qualitatively similar to those under the lump-sum transfer case. Production resources shift from exports to outputs dedicated for domestic sales, and imports goes up, i.e., the Dutch disease story still holds in these simulations (Appendix 3).

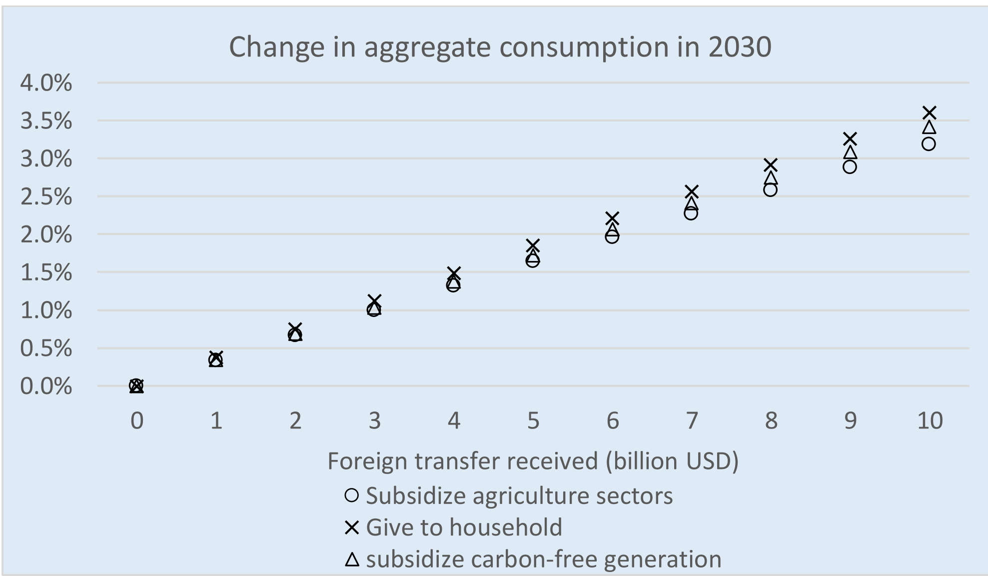


Figure 13. Change in aggregate consumption under different subsidy usages

4. Economic Impacts of climate change

Choi et al. (2021) finds that under a BAU (RCP 8.5) scenario, the annual mean web-bulb temperature of Bangladesh may increase from 26.7 °C in 2020 to 27.8 °C in 2050. Based on this projection, we consider changes in crop land and labor productivities due to a higher temperature. Our crop land productivity impact is from Reilly et al. (2007), which shows that without efforts on emissions mitigation, compared with the 2020 level, crop land productivity may drop by about 18% in 2050 (Figure 14).

On the other hand, the labor productivity impact is from the literature review of Hsiang (2010) for laboratory evidence, which finds that task efficiency reduces by around 1%–2% per degree Celsius, once the web-bulb temperatures rise above 25 °C (Pilcher et al., 2002; Seppänen et al., 2003). According to the review, we assume that the labor productivity will fall by 1.5% per degree Celsius under the same climatic environment. With this consideration, the labor productivity of Bangladesh in 2050 is projected to fall by around 1.7% relative to the 2020 level (Figure 15).

Our simulation shows that the impacts of global warming via the two productivity channels could potentially lower Bangladesh's aggregate consumption by around 0.6% in 2035 and 1.6% in 2050 (Figure 16). To compensate the projected welfare loss during 2020 and 2050, we calculate the sum for the present values of aggregate consumption from 2020 to 2050 under the BAU scenario without the productivity impacts, use the sum as the target, and run CSAVE to find a fixed amount (in nominal term) of annual foreign transfer starting from 2026 up to 2050 to achieve the aggregate consumption target without productivity impacts. Our findings suggest that for Bangladesh, the present value of welfare loss due to global warming is around 89.8 billion USD, and an annual foreign transfer of 2.8 billion USD is needed in compensating the loss.

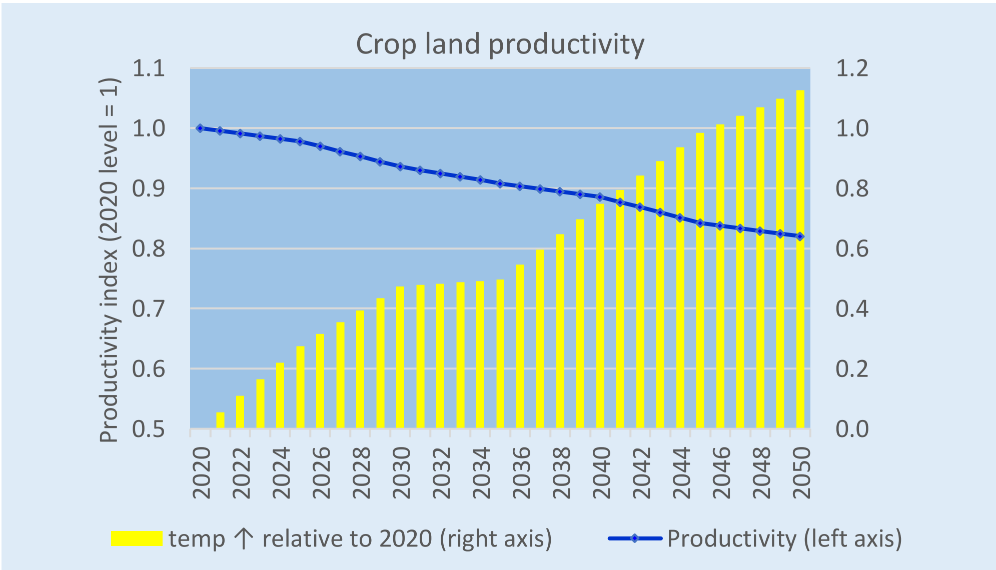


Figure 14. Crop land productivity index under the BAU temperature increase

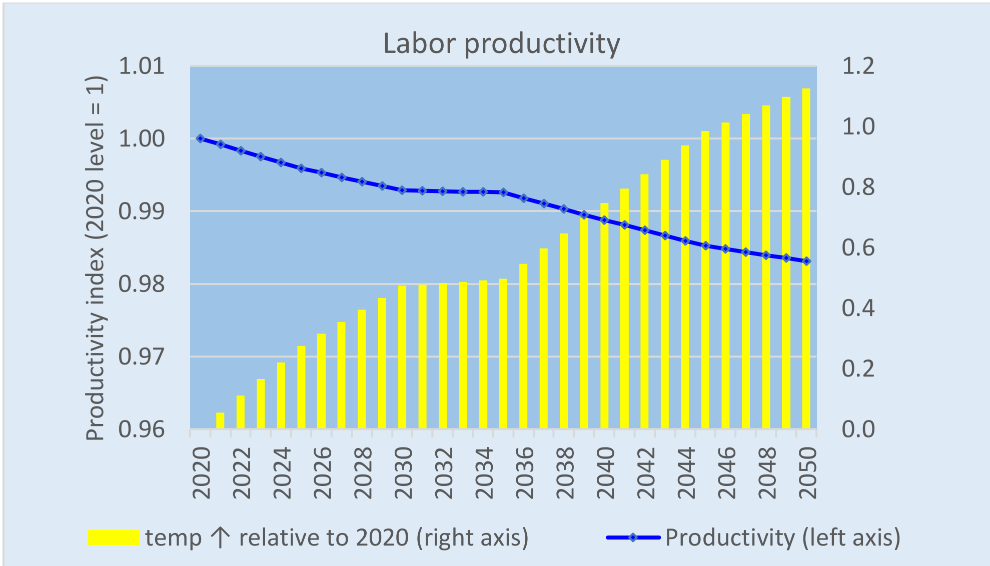


Figure 15. Labor productivity index under the BAU temperature increase

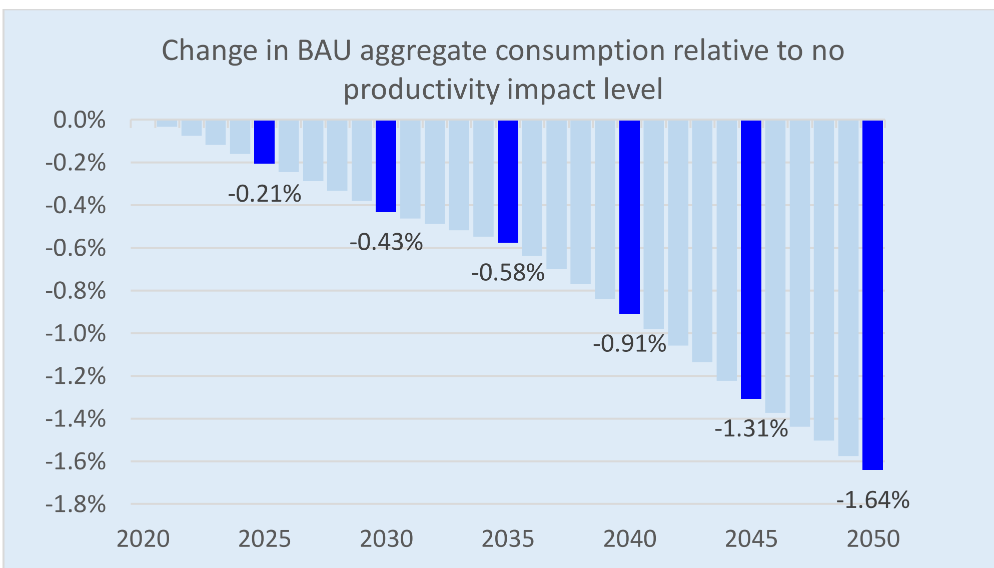


Figure 16. Change in BAU aggregate consumption relative to no productivity impact level

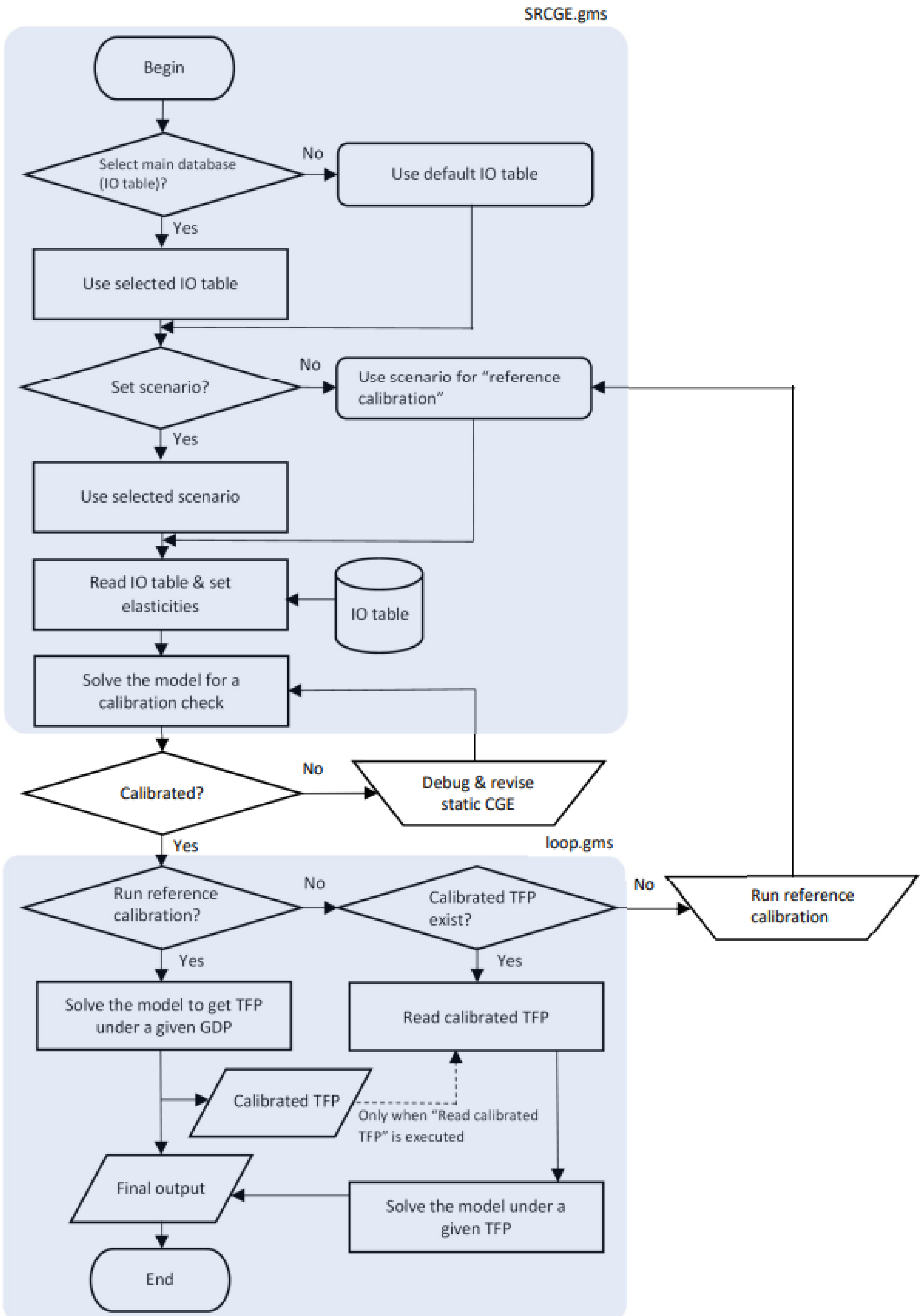
5. Conclusions

In this paper we present CSAVE, a single-country general equilibrium framework with the trade response parameterized based on the behavior of a multi-regional global CGE. Based on the model, we offer an example of Bangladesh—a country notably vulnerable to climate change, assess the potential impact of receiving a foreign climate transfer on domestic economy, and simulate the welfare loss due to a rising temperature. Our research reveals the potential side effect from receiving a hefty transfer, and calculates the required level of annual transfer in compensating the welfare loss.

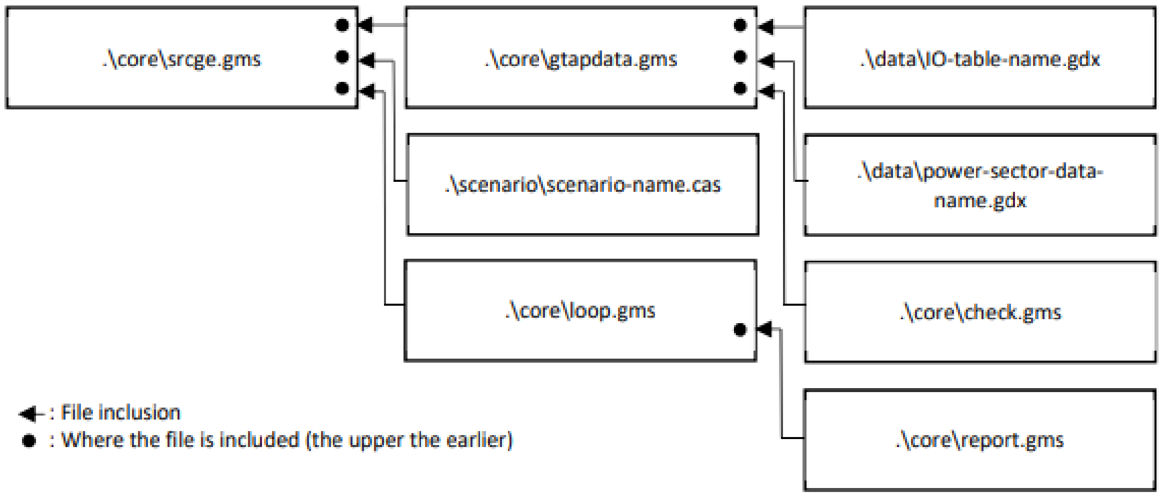
Our study demonstrates that when the research questions are country-specific, using a single-country model can provide fruitful insights as well. While the modeling exercises for Bangladesh we provide focus on macroeconomic implications of climate transfers, the concise framework of CSAVE allows modelers to conduct detailed or targeted analyses by setting a sectoral resolution higher than those in many multi-regional global models, without exponentially increasing the efficiency penalty or the likelihood of encountering numerical challenges.

Future CSAVE development can be carried out in various ways. For instance, one can incorporate some forms of sector-specific capital, such as including vintage capital and the dynamics generating it. This can help reflecting the observed hysteresis in resource allocation when new policies are in place. Alternatively, low-carbon energy supply options not presented in the base year can be calibrated according to engineering data, and then added as "backstop technologies" of the model—they may become economically feasible later under certain conditions, and therefore provide a better understanding for potential decarbonization pathways.

Appendix 1 Flow chart of running the model



Appendix 2 File structure



Appendix 3 Changes in key economic variables under subsidy scenarios

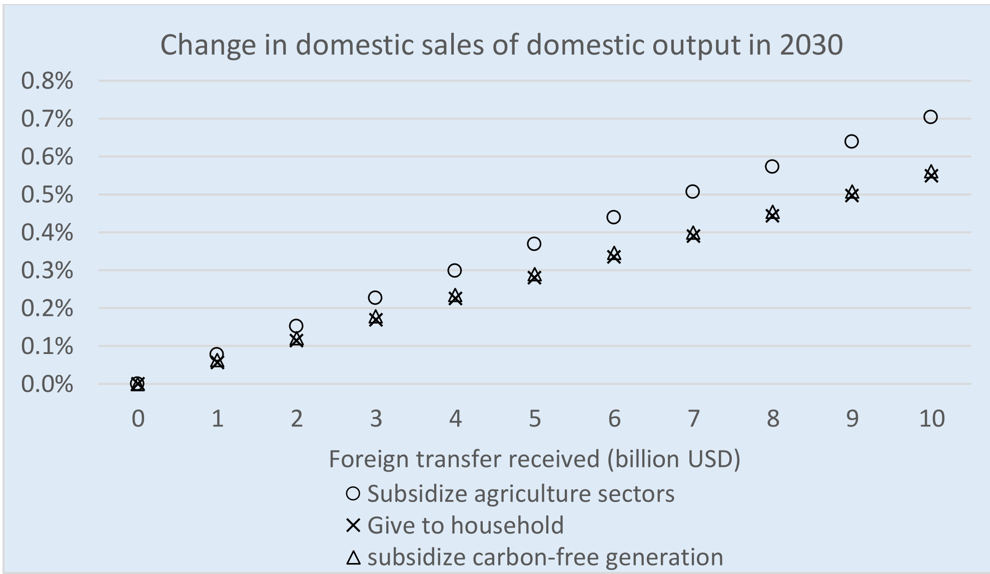


Figure A1. Change in domestic sales of domestic output under different subsidy usages

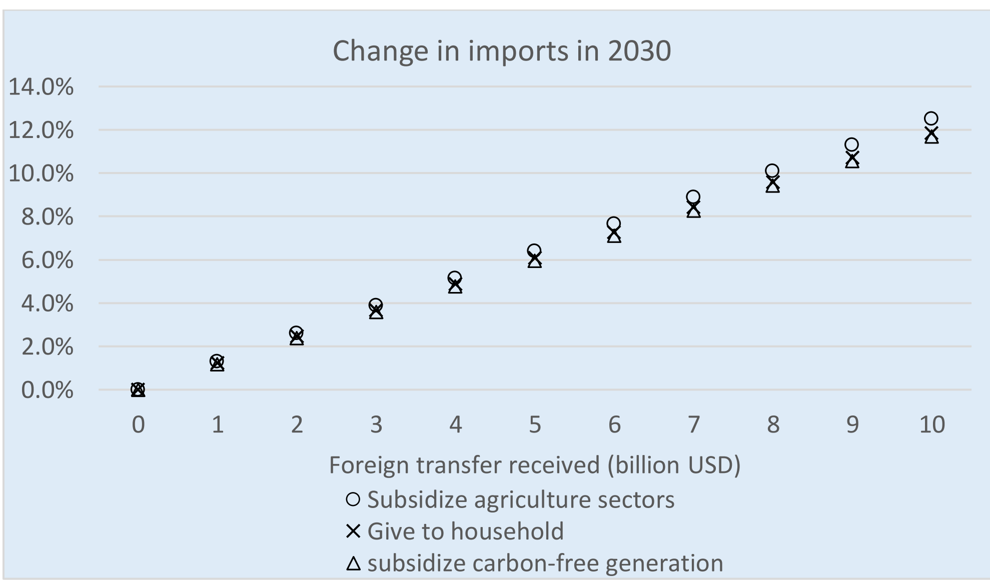


Figure A2. Change in imports under different subsidy usages

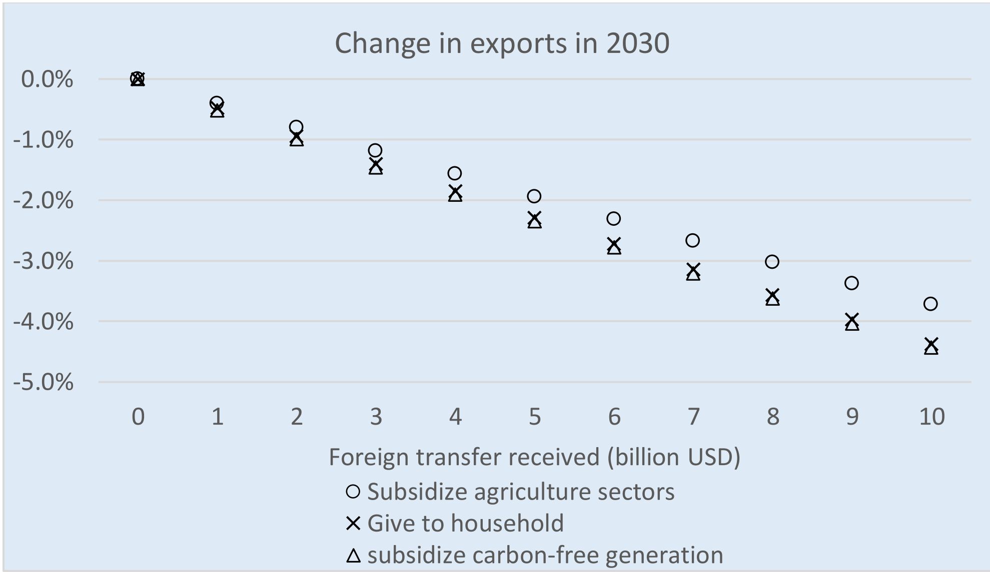


Figure A3. Change in exports under different subsidy usages

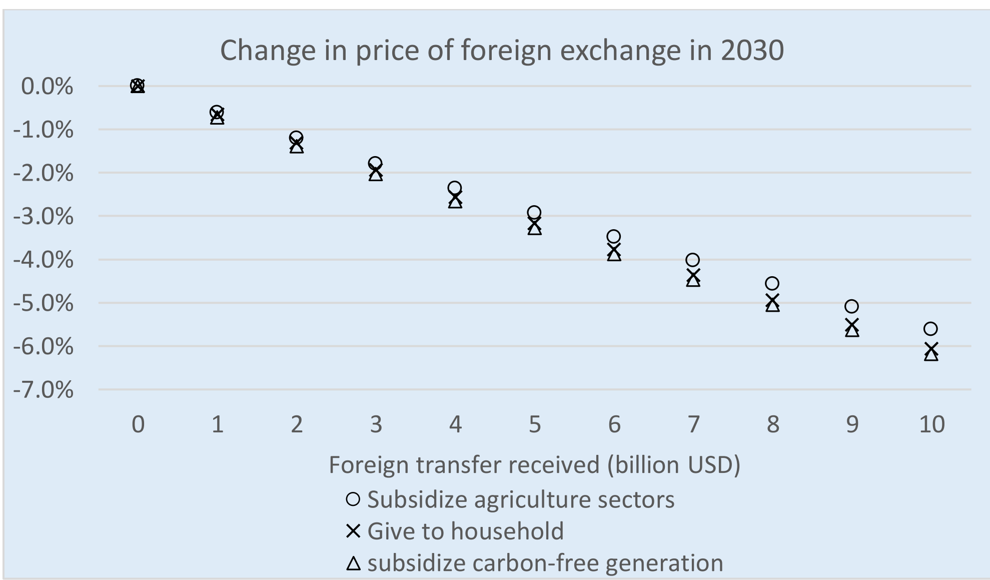


Figure A4. Change in price of foreign exchange

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