ECONOMIC DEVELOPMENT
INTELLIGENCE SYSTEM (EDIS)

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CDCGE

Computable Dynamic General Equilibrium Model

Linking Sectors. Driving Growth. Reducing Poverty.

A policy simulation tool for inclusive and sustainable economic transformation in Africa.

TECHNICAL REPORT

Specification and Simulation Results

The full technical specification of the Country-Disaggregated Computable General Equilibrium model — its structure, equations, calibration and human-development module — followed by the complete simulation study for Uganda: 209 policy levers solved individually to 2040, the country context for each drawn from the published record, a distributional analysis of twenty-two packages through the microsimulation and DASP, and the spatial incidence of every package by region and district.

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GTAP

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Background

1.1 Purpose and scope

This document is a complete specification of the *Country-Disaggregated Computable General Equilibrium* model, hereafter **CDCGE**. CDCGE is a multi-region, multi-sector, recursive-dynamic computable general equilibrium (CGE) model written in Julia and solved as a square *Mixed Complementarity Problem* (MCP) with PATHSolver. It is calibrated directly from the GTAP 11 global database and is structured along the lines of the *Environmental Impact and Sustainability Applied General Equilibrium* (ENVISAGE) model, version 10.01 (van der Mensbrugghe, 2019).

The report has three goals. First, to give a self-contained *economic* description of the model: the circular flow it represents, the nested production technology, the demand system, the trade structure, the income and fiscal accounts, the market-clearing and macro-closure conditions, the recursive dynamics, the emissions/climate linkage, and the human-development layer that turns public spending into education, health, water, sanitation, energy-access and infrastructure outcomes. Second, to give the *mathematical* specification: each block is written as a set of equations, each of which corresponds to a complementarity pair actually constructed in the model code. Third, to give an *operational* guide: how to assemble the data, build the Social Accounting Matrix (SAM), balance and aggregate it, calibrate the parameters, build and solve the static model, run dynamic and policy simulations, and couple the satellite sector models of the EDIS system.

A guiding principle of this report — and an important difference from a generic textbook treatment — is that **only equations that exist in the model code are documented**. CDCGE deliberately implements a focused subset of the full ENVISAGE specification: it carries the nested-CES production structure, the linear-expenditure demand system with an energy nest, bilateral Armington/CET trade, a Y-block income and fiscal layer, an electricity-supply technology mix, an adjusted-CET land allocation and iso-elastic natural-resource supply, in-model CO_2 emissions, macro aggregates, recursive dynamics, and a post-solve DICE-type climate module. Beyond ENVISAGE it carries an optional MAMS-style human-development module (Chapter 3) and the EDIS satellite-coupling layer. It does *not* carry several ENVISAGE features (capital vintages, the water-allocation module, the migration and R&D/knowledge modules, non-CO_2 gases, the AIDADS and CDE demand systems, the non-tariff-measure module, and the global trust fund). Where a feature is absent, this report says so explicitly rather than documenting an equation that the code does not solve.

1.2 Computable general equilibrium modelling

A CGE model is a numerical implementation of Walrasian general equilibrium theory. It represents an economy as a *circular flow*: firms buy primary factors (labour, capital, . . .) and intermediate goods to produce output; factor income accrues to households and the government; households and the government spend their income on goods and services; and equality of supply and demand on every market determines the equilibrium price vector. A CGE model is "computable" because all behavioural functions (production, utility, trade aggregation) are given explicit, calibrated functional forms — here, almost exclusively nested constant-elasticity-of-substitution (CES) and constant-elasticity-of-transformation (CET) functions, together with a linear expenditure system (LES) for household demand — so that the equilibrium can be solved numerically for a given data set and a given set of policy instruments.

CGE models are the standard tool for *counterfactual* analysis: they answer "what if" questions (what if a carbon tax of \$50/tCO_2 were imposed? what if import tariffs were cut by half?) by comparing the equilibrium of a perturbed economy with a reference equilibrium. Two properties make them attractive for climate-economy analysis. First, they are *economy-wide*: a shock to one sector (say, a carbon price on fossil fuels) propagates through input–output links, factor markets and trade to every other sector and region, so the model captures general-equilibrium feedbacks that a partial-equilibrium or single-sector study would miss. Second, they are *consistent*: every dollar of income has a source and a use, every market clears, and the macro identities (savings equals investment, the balance of payments, the government budget) hold by construction.

1.3 The ENVISAGE lineage

ENVISAGE is a global recursive-dynamic CGE model developed originally at the World Bank and re-coded for the OECD Environment Directorate; it is a descendant of the OECD's WALRAS, RUNS and GREEN models of the late 1980s and 1990s. Its distinguishing features, relative to a standard trade-focused CGE, are a developed energy sector (with explicit coal, oil, gas and electricity commodities and an energy demand nest), an electricity-generation technology detail, an emissions accounting layer covering the main greenhouse gases, a flexible system of carbon taxes and emission caps, and a climate module that links emissions to atmospheric concentrations, radiative forcing and temperature, with a feedback from temperature to economic damages. ENVISAGE is coded in GAMS/MCP and is calibrated on the GTAP database.

CDCGE adopts ENVISAGE's *structure* — its nested production trees, its demand nesting, its bilateral Armington/CET trade, its Y-block income accounting, its emissions and climate logic — and its *variable naming convention* (so that, e.g., the value-added bundle is `VA`, the capital–energy bundle is `KEF`, the Armington composite is `XA`, and government revenue by instrument is `YGOV`), but re-implements it from scratch in Julia, calibrated on the GTAP 11 database and solved as a square MCP with PATH. The equation-label scheme used throughout this report (P- for production, D- for demand, S- for supply, Y- for income, T- for trade, M- for macro/closure, E- for emissions, G- for dynamics, C- for capital analytics) is borrowed from the ENVISAGE documentation to ease cross-reference.

1.4 GTAP as the data foundation

CDCGE is calibrated on the GTAP Data Base, version 11 (GTAP 11), a global multi-region database of bilateral trade, production and consumption. It distinguishes 65 commodities and 5 primary endowments, with a reference year of 2017 and all values expressed in millions of US dollars. The CDCGE build reads the GTAP value-flow headers directly, with three features that shape how the SAM is constructed:

1. **Firm and final demand by source.** Firm intermediate demand is read from the domestic (`VDFB`) and imported (`VMFB`) intermediate-use headers; final demand splits into private (`VDPB`), government (`VDGB`) and investment (`VDIB`) domestic absorption with their import counterparts. Endowment payments come from `EVFB` and the make matrix from `MAKB`.

2. **Bilateral trade.** International trade is read from the bilateral trade headers `VXSB` (exports valued FOB at market prices), `VCIF` and `VFOB`, which give exports of commodity s from region i to region j. Bilateral imports and exports are reconstructed from these.

3. **Endowments, saving and capital.** Value added is the five GTAP primary endowments paid through `EVFB` plus production and indirect taxes; saving (`SAVE`), depreciation (`VDEP`), the capital stock (`VKB`) and population (`POP`) close the income and investment accounts.

From these objects the data layer reconstructs, for each region r and commodity i: firm intermediate use, endowment payments, the three domestic final-demand vectors, bilateral trade flows, and the seven tax accounts. The result is a long-format SAM with one `SEC:`r`:`i account per region–sector pair, factor accounts `FAC:`r`:`f, final-demand accounts (`HH`, `GOV`, `INV`), and tax accounts (`PTAX`, `ITAX`, `MTAX`, `ETAX`, `VTAX`, `CTAX`, `DTAX`). All seven tax accounts are always present (zero where the data record none).

1.5 Design philosophy: a square MCP solved with PATH

ENVISAGE is solved in GAMS using the MCP facility. CDCGE follows the same paradigm. A mixed complementarity problem pairs each *free variable* with exactly one *equation* (a complementarity condition). For an interior solution with strictly positive prices and quantities — which is the case at and near the calibrated benchmark — each complementarity pair reduces to an equality: "this equation holds, and its paired variable is free." The model is therefore **square by construction**: the number of variables equals the number of equations. The CDCGE code makes this explicit by building a list of complementarity pairs, one per equation, via a helper:

```
cons = Vector{Any}()
pair!(expr, var) = push!(cons, @constraint(jm, [expr, var] in MOI.Complements
    (2)))
```

Every behavioural relationship, market-clearing condition and accounting identity in the model is registered with one call to `pair!`, which records "`expr` = 0 is complementary to `var`." At the end, the number of `pair!` calls equals `num_variables(jm)`, and PATH solves the square system. Because all benchmark prices are normalised to 1 and the SAM is balanced, the calibrated data are an (approximate) fixed point: at the start the residual of every equation is essentially zero, the model is NaN-free, and a no-shock solve reproduces the data — the standard CGE homogeneity check.

A second design choice concerns *inactive nodes*. Many CES nests have a child whose benchmark value is zero (for example, a sector that uses no electricity). Such a child cannot be priced by a share equation (its share is 0/0). The code handles this generically: a zero-benchmark child variable is *pinned* to a small positive constant via a trivial complementarity pair $q - \varepsilon \perp q$, with $\varepsilon = 10^{-9}$. Pinning (rather than `JuMP.fix`) keeps the variable in the model's variable count so squareness is preserved, while removing it from the economically active system. This is why the model can be assembled uniformly for any data configuration without hand-coding which nests are empty.

1.6 Resolution and aggregation

The GTAP data layer distinguishes 65 commodities. For *solving*, the model is run at one of three ENVISAGE aggregations — coarse (9 sectors), medium (30 sectors, the default) or fine (63 sectors) — each preserving the production/energy/land/natural-resource nests. The energy-aware "coarse" grouping used in most worked examples has eleven sectors chosen to preserve every structural class the production and energy nests assume to be non-empty:

$$\{\text{AGR, LIVE, COAL, OIL, GAS, ELYFF, ELYCL, ETD, MANUF, TRANSP, SERV}\}.$$

Here electricity generation is split into a *fossil* bundle (`ELYFF`: coal-, gas- and petroleum-fired) and a *clean* bundle (`ELYCL`: nuclear, hydro, wind, solar, biomass, geothermal), with electricity transmission and distribution (`ETD`) as a separate sector, so that the power-generation mix can shift under carbon pricing. The medium 30-sector scheme is the default, and a fine 63-sector scheme is also available. The fine model is buildable and square but is heavier for PATH to solve at multi-region resolution; the coarse grouping yields a model that is an exact benchmark fixed point and solves in essentially zero iterations. Section A.12 returns to this point.

1.7 Numéraire, units and base year

The model fixes one price as the numéraire, $\texttt{PNUM} = 1$ (equation (M-1) below). All other prices are expressed relative to it. Monetary magnitudes are in the native GTAP unit, millions of US dollars, for the 2017 base year. Emissions are expressed in stylised model units derived from a small set of CO_2 intensity parameters (Chapter 2, Section 2.10); they are internally consistent index values for comparing scenarios, not a measured national greenhouse-gas inventory. The base year 2017 reflects the GTAP 11 reference year; the recursive dynamics step the economy forward from this benchmark in ≈5-year periods.

1.8 Roadmap

Chapter 2 gives the full equation system, block by block: sets, production, demand, supply (electricity), income, markets, closure, the MCP/equilibrium statement, dynamics, and emissions/climate. Chapter 3 specifies the optional human-development module — the MAMS-SDG layer that turns government spending by function into education, health, water, sanitation, energy-access and infrastructure outcomes, and feeds them back into labour supply and productivity. Chapter 4 documents how every share and level parameter is recovered from the balanced SAM. Appendix A is the operational guide, with code snippets, covering data set-up, SAM construction, balancing, calibration, the static solve, dynamic simulations and human-development runs. Chapter 6 presents the simulation study: every productivity, fiscal and external lever the application carries, solved to 2040, with the distributional and spatial results. Chapter 7 concludes, and is followed by references.

Chapter 2

Model structure and equations

This chapter specifies the complete equation system of CDCGE. It follows the traditional circular-flow ordering of a CGE description — production and factor demand, commodity supply, income and its distribution, final demand, trade, market equilibrium, macro closure — and then adds the dynamics and the emissions/climate linkage. The optional human-development block is specified separately, in Chapter 3. Each numbered equation corresponds to one complementarity pair in `src/ModelContext.jl` and `src/blocks/*.jl` (the static blocks), `src/StaticSolve.jl` (the dynamics) or `src/ClimateDICE.jl` (the climate step). Throughout, r (and its alias r') index regions, i, j index commodities/activities, and f indexes factors. A bar over a symbol (e.g. $\bar{Z}_{r,i,j}$) denotes a calibrated benchmark level read from the SAM; the calibration of these benchmarks is the subject of Chapter 4.

2.1 Sets and indices

Table 2.1 lists the sets used in the model definition. The model is fully set-driven: the regions, sectors and factors are inferred at run time from the accounts present in the balanced SAM, and the energy subsets are determined by passing the relevant sector codes to `build_static_model`.

Table 2.1: Sets used in the model definition.

Set	Description
r, r'	Regions (and a destination alias). Inferred from the `SEC:`r`:`i accounts. One region is the price-taking *world* region (default `ROW`); one is the numéraire region.
i, j	Commodities/activities (a single space, since GTAP's make matrix `MAKB` is diagonal). Inferred from the `SEC` accounts. The default medium set has thirty members.
f	Factors of production. The model uses five, mapped one-to-one from the GTAP endowments: land (`LAND`), unskilled labour (`LAB_UNSK`), skilled labour (`LAB_SK`), capital (`CAP`) and natural resources (`NRS`).
gy	Government revenue instruments: {ptax, itax, mtax, etax, vtax, ctax, dtax} — production, indirect, import, export, factor-use, carbon and direct taxes.
Energy subsets of i (passed to the model builder; intersected with S):	
`ELYFF`	Fossil-fired electricity generation.
`ELYCL`	Clean (non-fossil) electricity generation.
`ELEC`	= `ELYFF` ∪ `ELYCL`, all electricity generation.
`COAL`	Coal.
`OIL`	Oil and refined products.
`GAS`	Natural gas.

Set	Description
`energyset`	$=$ `ELEC` $\cup$ `COAL` $\cup$ `OIL` $\cup$ `GAS`.
`nonE`	$= S \setminus$ `energyset`: the non-energy commodities that form the Leontief intermediate bundle and the LES non-energy demand basket.

The factor set deserves comment. GTAP value added is paid to five primary endowments — Land, UnSkLab (unskilled labour), SkLab (skilled labour), Capital and NatRes (natural resources). CDCGE maps these one-to-one onto its five model factors `LAND`, `LAB_UNSK`, `LAB_SK`, `CAP` and `NRS`. Land is allocated across crop and livestock activities by an adjusted CET transformation (ENVISAGE §3.8.3), and each extraction sector draws on an iso-elastic natural-resource supply curve (ENVISAGE §3.8.4), so that the fixed factors clear their own markets rather than being folded into capital.

2.2 The CES building block

Almost every nest in CDCGE is a two-input CES aggregator. Rather than write each out separately, the code implements a single helper, `ces2!`, that for a parent bundle Q with price P, substitution elasticity σ and two children $(q_A, p_A, \bar{v}_A)$ and $(q_B, p_B, \bar{v}_B)$ — where q is the child quantity variable, p its price and $\bar{v}$ its benchmark value — emits the dual price equation and the conditional demands. With benchmark prices normalised to 1 and benchmark value shares $\theta_k = \bar{v}_k/(\bar{v}_A + \bar{v}_B)$, the generic CES block is:

$$\text{(CES-P)} \qquad P^{1-\sigma} = \sum_{k \in \{A,B\}} \theta_k \, p_k^{1-\sigma} \quad \perp \quad P, \tag{2.1}$$

$$\text{(CES-D)} \qquad q_k = \theta_k \left(\frac{P}{p_k}\right)^{\sigma} Q \quad \perp \quad q_k, \qquad k \in \{A, B\}. \tag{2.2}$$

Three special cases are handled exactly by the code:

- **One active child** ($\bar{v}_B = 0$): the price equation collapses to $P = p_A$ and all of Q goes to child A; the inactive child q_B is pinned to ε.
- **Cobb–Douglas** ($\sigma = 1$): the price dual becomes the geometric mean $P = \prod_k p_k^{\theta_k}$.
- **No active child** ($\bar{v}_A = \bar{v}_B = 0$): P is pinned to the numéraire and both children are pinned to ε.

The corresponding source is compact and worth showing in full, because it is the workhorse of the entire production and consumer-energy structure:

```
function ces2!(Q, P, sigma, qA, pA, v0A, qB, pB, v0B)
    act = Tuple{Any,Any,Float64}[]
    v0A > tol && push!(act, (qA,pA,v0A)); v0B > tol && push!(act, (qB,pB,v0B))
    if isempty(act)                        # no active child
        pair!(P - PNUM, P)
        pair!(qA - pin, qA); pair!(qB - pin, qB); return
    end
    tot = sum(x[3] for x in act)           # sum of benchmark values
    if length(act) == 1                    # one active child: P = p_A
        pair!(P - act[1][2], P)
    elseif abs(sigma-1.0) < 1e-6           # Cobb-Douglas
        pair!(P - prod(x[2]^(x[3]/tot) for x in act), P)
    else                                   # general CES dual price
        pair!(P^(1-sigma) - sum((x[3]/tot)*x[2]^(1-sigma) for x in act), P)
    end
```

```
    for (q,p,v0) in act                      # conditional demand for each child
        pair!(q - (v0/tot)*(P/p)^sigma*Q, q)
    end
    (v0A <= tol) && pair!(qA - pin, qA)    # pin inactive children
    (v0B <= tol) && pair!(qB - pin, qB)
end
```

Equations (2.1)–(2.2) are the template for every nest below; in the block descriptions we name the children and the elasticity and refer back to this template rather than repeating the algebra. Note that the benchmark shares θ_k are not stored as separate parameters: because benchmark prices are 1, the value share equals the quantity share, and the code passes the benchmark *values* $\bar{v}_k$ directly into `ces2!`, which forms the shares internally. This is the calibration-by-construction property discussed in Chapter 4.

2.3 Production block

Production in CDCGE is a nested structure with a Leontief top tier (so that the intermediate-input aggregate and value added are used in fixed proportions to gross output) and a deep CES value-added/energy tree below it. The full tree, reproduced from the source header, is:

$$
\begin{aligned}
XP &\xrightarrow{\text{Leontief}} ND1 \text{ (non-energy intermediates)},\ VA \\
VA &\xrightarrow{\sigma_v} \text{LAB1 (unskilled)},\ KEF \\
KEF &\xrightarrow{\sigma_{kef}} KS,\ EN \text{ (energy)} \\
KS &\xrightarrow{\sigma_k} \text{CAP},\ \text{LAB2 (skilled)} \\
EN &\xrightarrow{\sigma_{erg}} XELY \text{ (electricity)},\ NELY \\
XELY &\xrightarrow{\sigma_{pow}} \text{ELYFF (fossil)},\ \text{ELYCL (clean)} \\
NELY &\xrightarrow{\sigma_{nely}} \text{COAL},\ OLG \\
OLG &\xrightarrow{\sigma_{olg}} \text{OIL},\ \text{GAS}
\end{aligned}
$$

This structure lets producers substitute among energy carriers (coal vs. oil vs. gas vs. electricity), between the electricity carriers (fossil vs. clean generation), and between the energy bundle and the capital–skilled-labour bundle, so that a carbon price — which raises the effective price of fossil-energy inputs — lowers fossil-energy use and emissions both by fuel-switching and by energy/capital substitution. Land, natural resources and water do not appear: they are folded into `CAP`, so the capital-and-fixed-factor sub-nests of ENVISAGE (`KF`, `KSW`, `KL`) collapse and `KS` aggregates capital with skilled labour directly.

2.3.1 Top tier: zero profit and output allocation

Let $\bar{a}^{nd1}_{r,a} = N\bar{D}1_{r,a}/\bar{X}_{r,a}$ and $\bar{a}^{va}_{r,a} = V\bar{A}_{r,a}/\bar{X}_{r,a}$ be the calibrated Leontief coefficients (intermediate-bundle and value-added shares of gross output), and let $\tau_{r,a} = \tau^p_{r,a} + \tau^i_{r,a}$ be the combined production-plus-indirect tax rate on activity a. The top of the production nest has four equations. The zero-profit condition (P-1) states that the tax-adjusted unit revenue equals unit cost; it is complementary to gross output XP:

$$(1-\tau_{r,a})\,PX_{r,a} \;=\; \bar{a}^{nd1}_{r,a}\,PND1_{r,a} + \bar{a}^{va}_{r,a}\,PVA_{r,a} \qquad \perp\ XP_{r,a}. \tag{P-1}$$

The output-allocation identity (P-2) sends gross output to the domestic market and to exports; it is complementary to the producer price PX:

$$XP_{r,a} \;=\; XD_{r,a} + XET_{r,a} \qquad \perp\ PX_{r,a}. \tag{P-2}$$

The two Leontief demands (P-3, P-4) fix the intermediate-bundle and value-added quantities in proportion to gross output:

$$ND1_{r,a} = \bar{a}^{nd1}_{r,a}\, XP_{r,a} \qquad \perp\; ND1_{r,a}, \tag{P-3}$$

$$VA_{r,a} = \bar{a}^{va}_{r,a}\, XP_{r,a} \qquad \perp\; VA_{r,a}. \tag{P-4}$$

The Leontief (zero-substitution) assumption at the top is the standard CGE choice: it says that the technology does not let a firm substitute "value added in general" for "intermediates in general" — substitution happens *within* the value-added/energy tree and *within* the intermediate bundle, not across the top split.

2.3.2 The non-energy intermediate bundle

The intermediate bundle $ND1$ aggregates the non-energy commodities $i \in \texttt{nonE}$ in fixed (Leontief) proportions. Its price is the benchmark-weighted average of the Armington prices of its components, written so that $PND1 = 1$ at the benchmark (P-5):

$$PND1_{r,a} \;=\; \sum_{i\in\texttt{nonE}} \frac{\bar{Z}_{r,i,a}}{N\bar{D}1_{r,a}}\, PA_{r,i} \qquad \perp\; PND1_{r,a}, \tag{P-5}$$

and the derived demand for each non-energy intermediate i is Leontief in the bundle (P-6):

$$XN_{r,i,a} \;=\; \frac{\bar{Z}_{r,i,a}}{N\bar{D}1_{r,a}}\, ND1_{r,a} \qquad \perp\; XN_{r,i,a}, \qquad i \in \texttt{nonE}. \tag{P-6}$$

If the bundle is empty ($N\bar{D}1_{r,a} \le \varepsilon$), $PND1$ is pinned to the numéraire; if a particular non-energy input has zero benchmark use, its XN is pinned to ε. The variable $XN_{r,i,a}$ is the demand for commodity i by activity a; it enters the commodity market-clearing condition (T-4) below.

2.3.3 Value added and the capital–energy nest

The value-added tree is a cascade of two-input CES nests, each an instance of (2.1)–(2.2). Reading the source, the nests and their children are:

$$VA_{r,a} = \mathrm{CES}_{\sigma_v}\big(XF_{r,\mathrm{LAB\_UNSK},a},\; KEF_{r,a}\big), \tag{P-7}$$

$$KEF_{r,a} = \mathrm{CES}_{\sigma_{kef}}\big(KS_{r,a},\; EN_{r,a}\big), \tag{P-8}$$

$$KS_{r,a} = \mathrm{CES}_{\sigma_k}\big(XF_{r,\mathrm{CAP},a},\; XF_{r,\mathrm{LAB\_SK},a}\big). \tag{P-9}$$

Each line (P-7)–(P-9) expands, via the `ces2!` template (2.1)–(2.2), into a price-dual equation complementary to the parent price (PVA, $PKEF$, PKS) and one conditional-demand equation per active child complementary to that child's quantity. So, for example, (P-7) generates the dual

$$PVA^{1-\sigma_v}_{r,a} = \theta^{u}_{r,a}\, WF^{1-\sigma_v}_{r,\mathrm{LAB\_UNSK}} + \theta^{kef}_{r,a}\, PKEF^{1-\sigma_v}_{r,a} \;\;\perp\;\; PVA_{r,a},$$

the unskilled-labour demand $XF_{r,\mathrm{LAB\_UNSK},a} = \theta^{u}_{r,a}(PVA_{r,a}/WF_{r,\mathrm{LAB\_UNSK}})^{\sigma_v} VA_{r,a}$, and the capital–energy-bundle demand $KEF_{r,a} = \theta^{kef}_{r,a}(PVA_{r,a}/PKEF_{r,a})^{\sigma_v} VA_{r,a}$, with θ^{u}, θ^{kef} the benchmark value shares of unskilled labour and the KEF bundle in value added. Equations (P-8) and (P-9) expand analogously, substituting capital for skilled labour (σ_k) and the capital-skilled-labour bundle for energy (σ_{kef}). The factor demands $XF_{r,f,a}$ produced by these nests feed the factor-market-clearing conditions (Y-fac) below; the factor prices $WF_{r,f}$ are economy-wide (a single market for each factor in each region).

2.3.4 The energy nest

The energy bundle EN is itself a CES cascade over an electricity sub-bundle and the non-electric fuels:

$$EN_{r,a} = \mathrm{CES}_{\sigma_{erg}}(\, XELY_{r,a},\ NELY_{r,a}\,), \tag{P-10}$$
$$XELY_{r,a} = \mathrm{CES}_{\sigma_{pow}}(\, XN_{r,\mathrm{ELYFF},a},\ XN_{r,\mathrm{ELYCL},a}\,), \tag{P-11}$$
$$NELY_{r,a} = \mathrm{CES}_{\sigma_{nely}}(\, XN_{r,\mathrm{COAL},a},\ OLG_{r,a}\,), \tag{P-12}$$
$$OLG_{r,a} = \mathrm{CES}_{\sigma_{olg}}(\, XN_{r,\mathrm{OIL},a},\ XN_{r,\mathrm{GAS},a}\,). \tag{P-13}$$

Equation (P-10) splits the energy bundle into electricity ($XELY$) and non-electric energy ($NELY$) with elasticity σ_{erg}. Equation (P-11) — the *power-supply mix* — splits the electricity bundle into demand for fossil-fired and clean electricity with elasticity σ_{pow}; this is the node that lets the generation mix decarbonise under a carbon price. Equation (P-12) splits non-electric energy into coal and the oil-and-gas bundle (σ_{nely}), and (P-13) splits oil-and-gas into oil and gas (σ_{olg}). The leaf quantities are the intermediate demands $XN_{r,i,a}$ for the energy commodities $i \in \{\texttt{ELYFF}, \texttt{ELYCL}, \texttt{COAL}, \texttt{OIL}, \texttt{GAS}\}$, and the leaf prices are the corresponding Armington prices $PA_{r,i}$. Each of (P-10)–(P-13) expands through the `ces2!` template into a price-dual ($\perp PEN, PELY, PNELY, POLG$) and the active-child demands. Because these leaf quantities are the same $XN_{r,i,a}$ variables that would otherwise sit in the non-energy bundle, the energy commodities are *removed* from `nonE` (the Leontief bundle) and routed through the energy nest instead; this is exactly the `energyset` partition of Section 2.1.

2.3.5 Production elasticities

Table 2.2 lists the substitution elasticities used in the production nests, with their default calibrated values (Chapter 4). They are read from the calibration's elasticity dictionary; the defaults follow ENVISAGE/ENV-Linkages practice.

Table 2.2: Production-side substitution elasticities (defaults).

Symbol	Nest	Default
σ_v	value added: unskilled labour vs. capital–energy bundle	0.8
σ_{kef}	capital-factor bundle vs. energy	0.5
σ_k	capital vs. skilled labour	0.5
σ_{erg}	electricity vs. non-electric energy	0.5
σ_{pow}	fossil vs. clean electricity generation	3.0
σ_{nely}	coal vs. oil-and-gas	0.5
σ_{olg}	oil vs. gas	0.5

The relatively high power-supply elasticity $\sigma_{pow} = 3$ reflects that, at the level of an electron delivered to the grid, fossil and clean generation are close substitutes from the buyer's point of view; the lower energy-carrier elasticities (0.5) reflect the well-documented short-run rigidity of inter-fuel substitution. The value-added elasticity $\sigma_v = 0.8$ is a standard capital–labour figure.

2.4 Final demand

There are three domestic final-demand agents: the representative household, the government, and investment. Household demand uses a Linear Expenditure System (LES) over a non-energy commodity basket plus an aggregate energy bundle, with the energy bundle further nested exactly like the production energy nest so that household fossil-fuel demand also responds to carbon prices. Government and investment demand are Cobb–Douglas (fixed value shares).

2.4.1 Household demand: the linear expenditure system

The LES derives from maximising a Stone–Geary utility function subject to the budget constraint; demand for each good is the sum of a *subsistence* (committed) quantity γ and a share β of *supernumerary income* Y^{sup} (income net of total subsistence expenditure). CDCGE calibrates the LES with a Frisch parameter (the marginal utility of income elasticity, default $\phi = -1.5$) and unit income elasticities, which gives the marginal budget share of good i as $\beta_i = \bar{C}_{r,i}/\bar{C}_r^{tot}$ and the subsistence quantity as $\gamma_i = \bar{C}_{r,i}\,(1-1/|\phi|)$, where $\bar{C}_{r,i}$ is benchmark household consumption of i and $\bar{C}_r^{tot} = \sum_i \bar{C}_{r,i}$. The energy bundle has $\beta_{nrg} = \bar{C}_r^{nrg}/\bar{C}_r^{tot}$ and $\gamma_{nrg} = \bar{C}_r^{nrg}(1-1/|\phi|)$.

Supernumerary income (D-1) is disposable income less household saving less total subsistence spending, valued at current prices (the non-energy commodities at their Armington prices PA, the energy bundle at its composite price $PCnrg$):

$$Y_r^{sup} \;=\; \big(YD_r - Sh_r\big) - \Big(\sum_{i\in\texttt{nonE}} PA_{r,i}\,\gamma_{r,i} + PCnrg_r\,\gamma_r^{nrg}\Big) \qquad \perp\; Ysup_r. \tag{D-1}$$

LES demand for each non-energy commodity (D-2) is the subsistence quantity plus the marginal share of real supernumerary income:

$$XAc_{r,i} \;=\; \gamma_{r,i} + \beta_{r,i}\,\frac{Y_r^{sup}}{PA_{r,i}} \qquad \perp\; XAc_{r,i}, \qquad i\in\texttt{nonE}. \tag{D-2}$$

LES demand for the aggregate energy bundle (D-3) is analogous, deflated by the energy composite price:

$$XCnrg_r \;=\; \gamma_r^{nrg} + \beta_r^{nrg}\,\frac{Y_r^{sup}}{PCnrg_r} \qquad \perp\; XCnrg_r. \tag{D-3}$$

2.4.2 The consumer energy nest

The household energy bundle $XCnrg$ is decomposed by a CES cascade that mirrors the production energy nest, so that a carbon price shifts household demand from fossil to clean electricity and from coal/oil/gas toward less carbon-intensive carriers:

$$XCnrg_r = \mathrm{CES}_{\sigma_{ce}}\big(XCely_r,\; XCnely_r\big), \tag{D-4}$$
$$XCely_r = \mathrm{CES}_{\sigma_{pow}}\big(XAc_{r,\mathrm{ELYFF}},\; XAc_{r,\mathrm{ELYCL}}\big), \tag{D-5}$$
$$XCnely_r = \mathrm{CES}_{\sigma_{cnely}}\big(XAc_{r,\mathrm{COAL}},\; XColg_r\big), \tag{D-6}$$
$$XColg_r = \mathrm{CES}_{\sigma_{colg}}\big(XAc_{r,\mathrm{OIL}},\; XAc_{r,\mathrm{GAS}}\big). \tag{D-7}$$

Equation (D-4) splits the energy bundle into a consumer electricity bundle ($XCely$) and non-electric energy ($XCnely$) with elasticity σ_{ce}; (D-5) is the consumer power-supply mix (fossil vs. clean) with the same σ_{pow} as in production; (D-6) splits non-electric into coal and oil-and-gas; (D-7) splits oil-and-gas. Each expands through `ces2!` with the benchmark household-consumption values of the energy commodities as shares; the leaf quantities are the household Armington demands $XAc_{r,i}$ for the energy commodities, and the prices are $PA_{r,i}$. The composite prices $PCnrg, PCely, PCnely, PColg$ are the CES duals.

If a region has no recorded household consumption at all ($\bar{C}_r^{tot} \le \varepsilon$), the code degenerates gracefully: supernumerary income is set to disposable income net of saving, and all consumer-energy quantities and prices are pinned, so the household block remains square.

2.4.3 Government and investment demand

Government and investment demand are Cobb–Douglas: each agent spends a fixed benchmark value share of its total outlay on each commodity. For government, nominal demand for i equals the government budget share $\bar{s}^{g}_{r,i}$ times benchmark government expenditure $G\bar{E}XP_r$ (valued at the numéraire), giving (D-8):

$$PA_{r,i}\,XAg_{r,i} \;=\; \bar{s}^{g}_{r,i}\,G\bar{E}XP_r\,PNUM \qquad \perp\; XAg_{r,i}. \tag{D-8}$$

For investment, nominal demand for i equals the investment budget share $\bar{s}^{inv}_{r,i}$ times total investment outlay SI_r (the savings-financed investment level determined by the closure), giving (D-9):

$$PA_{r,i}\,XAi_{r,i} \;=\; \bar{s}^{inv}_{r,i}\,SI_r \qquad \perp\; XAi_{r,i}. \tag{D-9}$$

Government expenditure is thus fixed in real terms (its volume is exogenous, financed by tax revenue net of public saving), whereas the level of investment is savings-driven and determined endogenously by the investment–savings balance (M-2). The split of investment across commodities is fixed by the benchmark investment shares.

2.4.4 Demand elasticities

Table 2.3 lists the consumer-side elasticities and the Frisch parameter, with defaults.

Table 2.3: Demand-side parameters (defaults).

Symbol	Role	Default
ϕ (Frisch)	marginal-utility-of-income elasticity (LES calibration)	-1.5
σ_{ce}	consumer electricity vs. non-electric energy	0.5
σ_{cnely}	consumer coal vs. oil-and-gas	0.5
σ_{colg}	consumer oil vs. gas	0.5
σ_{pow}	consumer fossil vs. clean electricity (shared with supply)	3.0

2.5 Commodity supply and the electricity mix

In a GTAP-based model such as ENVISAGE, the *supply* block (S-equations) maps activity output into commodities through a possibly non-diagonal "make" matrix, with a special nested-CES aggregation that combines the output of many power-generation activities into a single electricity commodity. CDCGE is built on GTAP data, in which the make matrix (`MAKB`) is diagonal and the product space is flat (Section 2.1). Consequently CDCGE has *no separate make matrix*: each sector i is simultaneously an activity and a commodity, and the only "supply" decision is how a sector allocates its gross output between the domestic market and exports. That decision is the CET output allocation, which appears in the top tier as the identity (P-2) and is given its full constant-elasticity-of-transformation form in the trade block below (T-7, T-8).

The electricity-*technology* detail that ENVISAGE places in its power-supply nest is, in CDCGE, represented on the *demand* side. Because the coarse aggregation keeps fossil-fired and clean generation as separate commodities (`ELYFF`, `ELYCL`) plus transmission and distribution (`ETD`), the choice of generation mix is made wherever electricity is demanded: by producers, through the power-supply CES node (P-11) inside their energy nest; and by households, through the consumer power-supply node (D-5). Both nodes use the same high substitution elasticity $\sigma_{pow} = 3$. A carbon price raises the effective cost of fossil-fired electricity (through the emissions surcharge described in Section 2.10), and these nodes then shift demand toward clean generation, which is the channel through which the modelled generation mix decarbonises. This is functionally equivalent to ENVISAGE's power-supply substitution but is implemented at the point of use rather than at a make-matrix aggregation node.

2.6 Income block

The income block traces factor income to households and the government and defines the savings of each domestic agent. It follows the ENVISAGE Y-block ordering, with government revenue disaggregated by tax instrument.

2.6.1 Factor income

Factor markets are economy-wide within each region: there is one wage/rental price $WF_{r,f}$ per factor f, and factor income $YF_{r,f}$ is that price times total factor use (Y-1):

$$YF_{r,f} = WF_{r,f} \sum_i XF_{r,f,i} \qquad \perp \; YF_{r,f}. \tag{Y-1}$$

Total factor income in region r is $\widehat{Y}_r^F = \sum_f YF_{r,f}$; it is the wage-and-rental bill that the production nests generate.

2.6.2 Government revenue by instrument

Government revenue is collected in the variable $YGOV_{r,gy}$, one entry per instrument gy. The seven revenue equations are:

$$YGOV_{r,\text{ptax}} = \sum_i \tau^p_{r,i} \, PX_{r,i} \, XP_{r,i} \qquad \perp \; YGOV_{r,\text{ptax}}, \tag{Y-2}$$

$$YGOV_{r,\text{itax}} = \sum_i \tau^i_{r,i} \, PX_{r,i} \, XP_{r,i} \qquad \perp \; YGOV_{r,\text{itax}}, \tag{Y-3}$$

$$YGOV_{r,\text{vtax}} = \tau^v \, \widehat{Y}_r^F \qquad \perp \; YGOV_{r,\text{vtax}}, \tag{Y-4}$$

$$YGOV_{r,\text{mtax}} = \tau^m \sum_i PMT_{r,i} \, XMT_{r,i} \qquad \perp \; YGOV_{r,\text{mtax}}, \tag{Y-5}$$

$$YGOV_{r,\text{etax}} = \tau^e \sum_i PE_{r,i} \, XET_{r,i} \qquad \perp \; YGOV_{r,\text{etax}}, \tag{Y-6}$$

$$YGOV_{r,\text{dtax}} = \kappa^f \, \widehat{Y}_r^F + \kappa^h \, YH_r \qquad \perp \; YGOV_{r,\text{dtax}}, \tag{Y-7}$$

$$YGOV_{r,\text{ctax}} = 0 \qquad \perp \; YGOV_{r,\text{ctax}}. \tag{Y-8}$$

Production-tax revenue (Y-2) and indirect-tax revenue (Y-3) are the respective ad-valorem rates times the value of output. Factor-use-tax revenue (Y-4) is the factor-tax rate τ^v times total factor income. Import-tariff revenue (Y-5) and export-tax revenue (Y-6) are the tariff/export rates times the value of aggregate imports and exports. Direct-tax revenue (Y-7) is the sum of a factor direct-tax component (κ^f on factor income) and a household income-tax component (κ^h on household income). The carbon-tax account (Y-8) is held at zero because a carbon price is implemented as an addition to the *indirect*-tax rate on fossil-energy commodities (Section A.10); the carbon revenue therefore appears inside `itax` (Y-3) rather than in a separate `ctax` stream. Total government revenue (Y-9) sums the instruments:

$$YG_r = \sum_{gy} YGOV_{r,gy} \qquad \perp \; YG_r. \tag{Y-9}$$

The default tax-instrument rates ($\tau^v, \tau^m, \tau^e, \kappa^f, \kappa^h$) are zero, so that the benchmark is reproduced exactly; they are activated in policy scenarios (e.g. $\kappa^h > 0$ for carbon-revenue recycling, or a tariff schedule through τ^m). The production- and indirect-tax rates $\tau^p_{r,i}, \tau^i_{r,i}$ are calibrated from the benchmark tax accounts (Chapter 4).

2.6.3 Household income, disposable income and saving

Household income (Y-10) is factor income net of the factor direct tax:

$$YH_r \;=\; \left(1-\kappa^f\right)\widehat{Y}_r^F \qquad \perp\; YH_r. \tag{Y-10}$$

Disposable income (Y-11) is household income net of the income tax:

$$YD_r \;=\; \left(1-\kappa^h\right)YH_r \qquad \perp\; YD_r. \tag{Y-11}$$

Household saving (Y-12) is a fixed average propensity $\overline{aps}_r$ out of disposable income:

$$Sh_r \;=\; \overline{aps}_r\,YD_r \qquad \perp\; Sh_r. \tag{Y-12}$$

2.6.4 Capital stock and depreciation

For the recursive dynamics the model carries a capital-stock value and a depreciation allowance. The capital stock (Y-13) is the capital factor income (equivalently, the value of the capital endowment at the benchmark rental of 1):

$$Ks_r \;=\; YF_{r,\mathrm{CAP}} \qquad \perp\; Ks_r, \tag{Y-13}$$

and the depreciation allowance (Y-14) is the depreciation rate δ times the capital stock:

$$DeprY_r \;=\; \delta\,Ks_r \qquad \perp\; DeprY_r. \tag{Y-14}$$

The default depreciation rate is $\delta = 0.05$. These two variables are read by the recursive-dynamic loop (Section 2.11) to advance the capital stock between periods.

2.6.5 Government and total saving

Government saving (Y-15) is revenue less the value of government final demand:

$$Sg_r \;=\; YG_r - \sum_i PA_{r,i}\,XAg_{r,i} \qquad \perp\; Sg_r. \tag{Y-15}$$

Investable funds (the financing identity, Y-16) equal household saving plus government saving plus foreign saving (the latter valued at the numéraire):

$$SI_r \;=\; Sh_r + Sg_r + \bar{Sf}_r\,PNUM \qquad \perp\; SI_r. \tag{Y-16}$$

Here $\bar{Sf}_r$ is the (calibrated, exogenous) net foreign saving of region r — its current-account balance — which closes each region's savings–investment account; the construction of $\bar{Sf}_r$ from the benchmark capital flows is described in Chapter 4.

2.7 Trade

Trade in CDCGE is *bilateral* on both the import and the export side. Demand distinguishes goods by region of origin (the Armington assumption): a region's total absorption of a commodity is a CES aggregate of the domestically-produced variety and an import composite, and the import composite is itself a CES aggregate over the varieties sourced from each partner region. Supply mirrors this with a CET allocation of gross output between the domestic market and an export bundle. A central modelling choice is the treatment of the Rest-of-World region as a *price-taking world*, which anchors the bloc's terms of trade and removes the closed-world price indeterminacy that would otherwise make the bilateral system rank-deficient.

2.7.1 Top-level Armington demand

Let $\bar{s}^d_{r,i}$ and $\bar{s}^m_{r,i}$ be the benchmark domestic and import value shares in absorption, and σ_{arm} the top Armington elasticity. Absorption $XA_{r,i}$ is split into domestic demand $XD_{r,i}$ (T-1) and an import composite $XMT_{r,i}$ (T-2), with the Armington composite price $PA_{r,i}$ given by the CES dual (T-3):

$$XD_{r,i} = \bar{s}^d_{r,i}\left(\frac{PA_{r,i}}{PD_{r,i}}\right)^{\sigma_{arm}} XA_{r,i} \qquad \perp\ XD_{r,i}, \tag{T-1}$$

$$XMT_{r,i} = \bar{s}^m_{r,i}\left(\frac{PA_{r,i}}{PMT_{r,i}}\right)^{\sigma_{arm}} XA_{r,i} \qquad \perp\ XMT_{r,i}, \tag{T-2}$$

$$PA_{r,i}^{1-\sigma_{arm}} = \bar{s}^d_{r,i}\, PD_{r,i}^{1-\sigma_{arm}} + \bar{s}^m_{r,i}\, PMT_{r,i}^{1-\sigma_{arm}} \qquad \perp\ PA_{r,i}. \tag{T-3}$$

If a commodity has no benchmark imports ($\bar{s}^m_{r,i} = 0$), the import composite is pinned to zero and (T-3) reduces to $PA = PD$.

2.7.2 Commodity market clearing

Absorption equals total final-plus-intermediate demand for the Armington composite (T-4): household, government and investment demand plus the sum of intermediate demands across all using activities:

$$XA_{r,i} \;=\; XAc_{r,i} + XAg_{r,i} + XAi_{r,i} + \sum_a XN_{r,i,a} \qquad \perp\ XA_{r,i}. \tag{T-4}$$

This is the central goods-market equilibrium condition: it equates the supply of the Armington composite (which (T-3) prices) to the sum of all demands for it, and is complementary to the absorption quantity.

2.7.3 Bilateral import sourcing

The import composite is sourced from partner regions by a second-level CES nest. Let $\bar{s}^w_{exp\to r,i} = \bar{XW}_{exp,r,i}/\bar{M}_{r,i}$ be the benchmark share of partner *exp* in region r's imports of i (where $\bar{M}_{r,i}$ is benchmark total imports), and σ_w the second-level (sourcing) elasticity. The landed price of a variety from exporter *exp* is the exporter's free-on-board price $PE_{exp,i}$ grossed up by the import tariff τ^m. Bilateral import demand (T-5) and the import-composite price (T-6) are:

$$XW_{exp,i,r} = \bar{s}^w_{exp\to r,i}\left(\frac{PMT_{r,i}}{(1+\tau^m)\, PE_{exp,i}}\right)^{\sigma_w} XMT_{r,i} \qquad \perp\ XW_{exp,i,r}, \tag{T-5}$$

$$PMT_{r,i}^{1-\sigma_w} = \sum_{exp\neq r} \bar{s}^w_{exp\to r,i}\left((1+\tau^m)\, PE_{exp,i}\right)^{1-\sigma_w} \qquad \perp\ PMT_{r,i}. \tag{T-6}$$

Equation (T-5) holds for each ordered pair of exporter *exp* and importer r with $exp \neq r$ and positive benchmark trade; self-imports and zero-benchmark flows are pinned to zero. The variable $XW_{exp,i,r}$ is thus the volume of commodity i shipped from *exp* to r. Equation (T-6) is the CES dual that prices the import composite as a share-weighted aggregate of the tariff-inclusive bilateral prices; if a region has no benchmark imports of i, PMT is pinned to the numéraire.

2.7.4 Export allocation (CET) and export markets

On the supply side, gross output is transformed between the domestic market and exports by a CET function with transformation elasticity ψ_{et}. Let $\bar{s}^{cd}_{r,i}$ and $\bar{s}^{ce}_{r,i}$ be the benchmark domestic and export shares of gross output. Domestic supply to the home market (T-7) and the export bundle (T-8) are:

$$XD_{r,i} = \bar{s}^{cd}_{r,i}\left(\frac{PD_{r,i}}{PX_{r,i}}\right)^{\psi_{et}} XP_{r,i} \qquad \perp\ PD_{r,i}, \tag{T-7}$$

$$XET_{r,i} = \bar{s}^{ce}_{r,i} \left(\frac{PE_{r,i}}{PX_{r,i}}\right)^{\psi_{et}} XP_{r,i} \qquad \perp \; XET_{r,i}. \tag{T-8}$$

Note the complementarity in (T-7): the domestic supply relation is paired with the domestic price $PD_{r,i}$, which makes (T-7) the *domestic market-clearing* condition (the same XD appears in both the demand relation (T-1) and this supply relation, so PD adjusts to clear the home market). The export bundle is then distributed to destinations, and the export market clears through the producer export price PE.

2.7.5 The price-taking Rest-of-World anchor

The closure of the export side distinguishes the chosen *bloc* regions from the *world* region (default `ROW`). For the world region, the producer export price is pinned to the numéraire and its exports are demand-determined (T-9):

$$PE_{\mathrm{ROW},i} = PNUM \quad \perp \; PE_{\mathrm{ROW},i}; \qquad XET_{\mathrm{ROW},i} = \sum_{imp \neq \mathrm{ROW}} XW_{\mathrm{ROW},i,imp} \quad \perp \; XET_{\mathrm{ROW},i}. \tag{T-9}$$

For each bloc region (i.e. $r \neq$ ROW) with positive benchmark exports, the export market clears by equating the export bundle to total bilateral exports, complementary to the producer export price (T-10):

$$XET_{r,i} \; = \sum_{imp \neq r} XW_{r,i,imp} \qquad \perp \; PE_{r,i}. \tag{T-10}$$

The economic content of the anchor is that the Rest-of-World is large relative to the modelled bloc, so it supplies imports and absorbs exports at fixed (numéraire) world prices, while the bloc's own export prices are endogenous and clear its export markets. Without this anchor, a closed bilateral world has a per-commodity global-balance redundancy (the identity "world exports = world imports"), which makes the price system rank-deficient: the benchmark would solve in zero iterations but any perturbation would fail (the model would report a non-invertible basis or slow progress). Pinning the world price removes the redundancy and yields a well-posed, robustly solvable system. ENVISAGE handles the analogous closure through its numéraire and the dropped Walras equation; CDCGE's RoW anchor is the bilateral counterpart.

2.7.6 Trade elasticities

The trade block uses two Armington elasticities and one transformation elasticity (Table 2.4).

Table 2.4: Trade-side elasticities (defaults).

Symbol	Role	Default
σ_{arm}	top Armington: domestic vs. aggregate imports	2.0
σ_w	second-level Armington: sourcing across exporters	4.0
ψ_{et}	CET: domestic market vs. exports	2.0

2.8 Factor markets and macro closure

2.8.1 Factor-market clearing

Each factor market clears within its region. Let $\bar{f}^s_{r,f} = \sum_j \bar{F}_{r,f,j}$ be the benchmark (fixed, for a given period) supply of factor f. The clearing condition (M-fac) equates supply to total factor demand, complementary to the factor price:

$$\bar{f}^s_{r,f} \; = \sum_i XF_{r,f,i} \qquad \perp \; WF_{r,f}, \qquad \text{if } \bar{f}^s_{r,f} > \varepsilon. \tag{M-fac}$$

Factor supply is exogenous within a period (it is grown between periods by the dynamics). If a factor has zero benchmark supply, its clearing row would be identically degenerate in its own price; the code instead pins that factor's price to the numéraire, $WF_{r,f} = PNUM \perp WF_{r,f}$, which keeps the Jacobian non-singular. In the default three-factor configuration all factors have positive supply, so this fallback is inactive.

2.8.2 Land allocation and natural-resource supply

Perfect mobility (M-fac) is the right treatment for capital and labour over a medium horizon, but it is the wrong one for land and natural resources: a hectare of irrigated paddy is not costlessly converted into pasture, and an oil field is not redeployed into mining. CDCGE therefore offers two optional factor-supply closures, implemented in `blocks/FactorSupplyBlock.jl` and switched on with `land_cet=true` and `natres_supply=true`. They sit *on top of* the factor demands of the production block; when a closure is off, the factor reverts to perfect mobility and the spare price and quantity variables are pinned, so the model stays square in every configuration.

Land (ENVISAGE §3.8.3). Aggregate land is allocated across activities by an *adjusted CET* — the quantity-additive variant of Appendix B, so that the allocations sum to the aggregate rather than to a CET index. With $\gamma_{r,a}$ the benchmark land shares ($\sum_a \gamma_{r,a} = 1$), ω the transformation elasticity and η_{lnd} the aggregate supply elasticity:

$$XF_{r,\text{LAND},a} = \gamma_{r,a}\, TLand_r \left(\frac{PFlnd_{r,a}}{PTLand_r}\right)^{\omega} \quad \perp\ PFlnd_{r,a} \tag{F-1}$$

$$PTLand_r = \left[\sum_a \gamma_{r,a}\, PFlnd_{r,a}^{\omega}\right]^{1/\omega} \quad \perp\ PTLand_r \tag{F-2}$$

$$TLand_r = \overline{TLand}_r \left(\frac{PTLand_r}{PNUM}\right)^{\eta_{lnd}} \quad \perp\ TLand_r \tag{F-3}$$

$$YF_{r,\text{LAND}} = \sum_a PFlnd_{r,a}\, XF_{r,\text{LAND},a} \quad \perp\ YF_{r,\text{LAND}} \tag{F-4}$$

Equation (F-1) is the CET first-order condition and doubles as the market-clearing condition for activity-specific land: land moves toward the activity offering the higher rent, but only imperfectly. (F-2) is the aggregate land price index, constructed so that the allocations in (F-1) add up to $TLand_r$ exactly. (F-3) makes the aggregate land *stock* itself price-responsive — extensification at the frontier. Land therefore earns *activity-specific* rents $PFlnd_{r,a}$ rather than a single uniform rent: finite ω means imperfect mobility, and $\omega \to \infty$ recovers the uniform-rent case. An activity with no benchmark land use has its land price pinned to the aggregate index.

Natural resources (ENVISAGE §3.8.4). Each extraction activity draws on its *own* natural-resource stock, supplied along an iso-elastic curve:

$$XF_{r,\text{NRS},a} = \bar{F}_{r,\text{NRS},a} \left(\frac{PFnrs_{r,a}}{PNUM}\right)^{\eta_{nrs}} \quad \perp\ PFnrs_{r,a} \tag{F-5}$$

$$YF_{r,\text{NRS}} = \sum_a PFnrs_{r,a}\, XF_{r,\text{NRS},a} \quad \perp\ YF_{r,\text{NRS}} \tag{F-6}$$

This is what gives fossil-fuel and mineral supply a finite short-run elasticity: a carbon price that depresses coal demand depresses the coal-specific resource rent rather than reallocating the resource, which is the empirically right response and is essential to the model's mitigation results. The default elasticities are $\omega = 1.0$, $\eta_{lnd} = 0.25$ and $\eta_{nrs} = 0.5$.

Water is deliberately absent from this list. The GTAP database carries no water endowment — water services fold into capital — so there is no water factor to allocate; a water market would require the GTAP-Water satellite database. What CDCGE does model is water *service delivery* and access, in the human-development module (Chapter 3), and water *supply* as a sectoral productivity path from the water satellite of the EDIS coupling layer.

2.8.3 The numéraire

One price is fixed to close the system (M-1):

$$PNUM \;=\; 1 \qquad \perp\; PNUM. \tag{M-1}$$

All other prices are determined relative to the numéraire. By Walras' law, with all markets clearing one price level is free; fixing $PNUM$ removes the residual degree of freedom. CDCGE does *not* carry a separate dropped savings–investment equation as ENVISAGE does (its "Walras" shifter): the combination of the per-region financing identity (Y-16) with the exogenous-foreign-saving closure and the RoW price anchor pins the system without an explicit slack, and a no-shock solve reproduces the benchmark to machine precision.

2.8.4 The investment–savings balance

Equation (Y-16) is the regional financing identity, and (D-9) allocates the resulting investment outlay across commodities. Together they implement a *savings-driven* closure: aggregate investment in each region equals the sum of household, government and foreign saving (plus, in the dynamics, the depreciation allowance is tracked separately for capital accumulation). The foreign-saving term $\bar{Sf}_r$ is fixed in real terms, so the trade balance is anchored and the real exchange rate (the relative price of the bloc's output) is free to adjust to clear the bilateral trade system. This is the standard neoclassical macro closure and matches ENVISAGE's default (fixed foreign saving, savings-driven investment, government volume fixed with the direct-tax instrument balancing the public account).

2.9 Macro aggregates

For reporting and for the recursive dynamics the model computes nominal GDP and a welfare index per region. Expenditure-side nominal GDP (M-3) is consumption plus government plus investment plus net exports:

$$GDPMP_r \;=\; \sum_i PA_{r,i}\big(XAc_{r,i}+XAg_{r,i}+XAi_{r,i}\big)+\sum_i \big(PE_{r,i}\,XET_{r,i}-PMT_{r,i}\,XMT_{r,i}\big) \quad \perp\; GDPMP_r. \tag{M-3}$$

The welfare index (M-4) is the real volume of household consumption:

$$Welf_r \;=\; \sum_i XAc_{r,i} \qquad \perp\; Welf_r. \tag{M-4}$$

$Welf$ is a quantity index (it sums consumption volumes, valued at benchmark prices of 1), so changes in it across scenarios measure the real-consumption gain or loss. A more formal equivalent-variation measure could be derived from the LES indirect utility function; CDCGE reports the consumption-volume index, which for the LES with unit income elasticities is a close monotone proxy.

2.10 Emissions and the climate module

CDCGE has an in-model CO_2 emissions accounting layer and a post-solve DICE-type climate module. The emissions layer sits *inside* the equilibrium (so emissions and any emissions-related fiscal flows are part of the solved system); the climate dynamics sit *outside* the per-period equilibrium (so atmospheric concentration, temperature and damage evolve as a recursive update between periods, exactly as ENVISAGE places its climate block outside the MCP).

2.10.1 In-model emissions

Each emitting commodity i carries a CO_2 intensity ρ_i (tonnes CO_2 per million USD of absorption). The intensities are:

$$\rho_{\text{COAL}} = 2200, \quad \rho_{\text{OIL}} = 1500, \quad \rho_{\text{GAS}} = 1100, \quad \rho_{\text{ELYFF}} = 2500,$$

and zero for all other commodities. Coal, oil and gas carry intensities for direct fuel combustion; fossil-fired electricity (`ELYFF`) carries an intensity for generation combustion. (Fossil-power combustion emissions are attached to the fossil-power sector directly — ENVISAGE taxes the emissions themselves, not the monetary fuel purchase — which is what makes the power-generation mix respond to a carbon price.) Regional emissions (E-1) are the intensity-weighted sum of Armington absorption:

$$Emi_r = \sum_i \rho_i \, XA_{r,i} \qquad \perp \ Emi_r, \tag{E-1}$$

and global emissions (E-2) sum over regions:

$$EmiGbl = \sum_r Emi_r \qquad \perp \ EmiGbl. \tag{E-2}$$

Because ρ multiplies absorption and absorption is endogenous, emissions fall whenever a policy raises energy prices and reduces fossil-energy demand — the emissions variable is a genuine equilibrium object, not a post-hoc accounting line.

2.10.2 The DICE-type climate step

Between periods, the recursive dynamic injects the period's global CO_2 emissions into a three-box carbon cycle, updates radiative forcing, advances a two-box temperature system, and computes a quadratic damage factor. The state variables are atmospheric carbon MAT, upper-ocean/biosphere carbon MU, deep-ocean carbon ML (all in GtC), atmospheric and deep-ocean temperature anomalies $TATM, TOCEAN$ (°C), radiative forcing $FORC$ (W/m^2), and the damage factor $DAMAGE \leq 1$. With a time step Δt (5 years), period emissions E^{GtCO_2} are first converted to a carbon mass flux $e = E^{\text{GtCO}_2} \cdot (12/44) \cdot \Delta t$. The carbon cycle (Cl-1)–(Cl-3) is:

$$MAT' = \phi_{11} MAT + \phi_{21} MU + e, \tag{Cl-1}$$

$$MU' = \phi_{12} MAT + \phi_{22} MU + \phi_{32} ML, \tag{Cl-2}$$

$$ML' = \phi_{23} MU + \phi_{33} ML. \tag{Cl-3}$$

Radiative forcing (Cl-4) is logarithmic in the ratio of atmospheric carbon to its pre-industrial level MAT_{pre}, plus an exogenous component F_{ex}:

$$FORC' = \eta \frac{\log\left(MAT'/MAT_{pre}\right)}{\log 2} + F_{ex}, \qquad \eta = 3.6813. \tag{Cl-4}$$

The two-box temperature system (Cl-5)–(Cl-6), with climate sensitivity feedback $\lambda = \eta/\text{ECS}$, is:

$$TATM' = TATM + \xi_1\big(FORC' - \lambda TATM - \xi_2(TATM - TOCEAN)\big), \tag{Cl-5}$$

$$TOCEAN' = TOCEAN + \xi_3 \, (TATM - TOCEAN). \tag{Cl-6}$$

Finally the damage factor (Cl-7) is a quadratic-in-temperature output multiplier:

$$DAMAGE' = \frac{1}{1 + \pi_2 \, TATM'^2}, \qquad \pi_2 = 0.00236. \tag{Cl-7}$$

Table 2.5: DICE-type climate parameters (defaults).

Symbol	Meaning	Default
ϕ_{11}, ϕ_{12}	atmosphere retention / to upper ocean	0.88, 0.12
$\phi_{21}, \phi_{22}, \phi_{23}$	upper-ocean exchange	0.196, 0.797, 0.007
ϕ_{32}, ϕ_{33}	deep-ocean exchange	0.001465, 0.998535
ξ_1, ξ_2, ξ_3	temperature-system coefficients	0.1005, 0.088, 0.025
ECS	equilibrium climate sensitivity (°C)	3.0
π_2	quadratic damage coefficient	0.00236
MAT_{pre}	pre-industrial atmospheric carbon (GtC)	588
Δt	time step (years)	5

The default parameters (Table 2.5) are the standard DICE carbon-cycle transition coefficients, an equilibrium climate sensitivity of 3.0°C, and a damage coefficient calibrated so that a few degrees of warming costs a few percent of output.

The damage factor can optionally feed back to the economy: when the damage feedback is switched on, next-period factor endowments are scaled by $DAMAGE'$, so warming reduces effective factor productivity (Section 2.11). When it is switched off, the climate state is tracked for reporting but does not affect the economy. ENVISAGE's climate feedback to agricultural yields and sea-level damages is more elaborate; CDCGE uses the single aggregate damage multiplier.

2.11 Recursive dynamics

CDCGE is recursive-dynamic: it solves a sequence of static equilibria, one per period, linked by between-period updates to the factor endowments, total factor productivity, energy intensity, and (optionally) the climate-damage feedback. This is the standard ENVISAGE dynamic recursion (the G-block), implemented in `run_recursive`. The four dynamic mechanisms are capital accumulation, labour-supply growth by skill, labour-augmenting productivity growth, and autonomous energy-efficiency improvement. The recursion runs in one of two modes, selected by the keyword `balanced`; the **balanced-growth baseline** described next is the default.

2.11.1 The balanced-growth baseline

The natural reference path for a recursive-dynamic model is one on which the economy grows steadily without spurious structural drift, so that any deviation in a counterfactual is attributable to the policy rather than to an unbalanced baseline. CDCGE obtains this by growing *every* exogenous benchmark anchor — all factor endowments *and* all autonomous final demand (government demand, the Stone–Geary subsistence quantities, investment and foreign saving) — by a single per-region factor each period,

$$g^{\text{eff}}_{r,t} \;=\; \big(1+g^{\text{pop}}_r\big)\big(1+g_{\text{tfp}}\big)\cdot DAMAGE'_t, \tag{G-0}$$

applied uniformly to the level fields $(\bar{X}, \bar{Z}, \bar{F}, \bar{C}, \bar{G}, \bar{I}, \bar{E}, \bar{M}, \dots)$ of the calibration. Because the calibrated model is homothetic in those levels and the share and elasticity parameters are scale-free (and left untouched), the model re-solves to a proportionally larger equilibrium and real output grows at g^{eff}, with per-capita output growing at the TFP rate g_{tfp}. This matters for correctness as much as for realism: growing factor *supply* faster than autonomous *demand* — the older, supply-only path — leaves the economy unbalanced, so the baseline stalls or deflates (output flat or declining while employment rises) and counterfactuals fail to converge. Moving the whole benchmark together restores a clean balanced-growth fixed point against which the carbon-price, damage and adaptation scenarios are measured. The alternative, unbalanced mode (`balanced=false`), which grows capital by accumulation and labour by skill and lets autonomous demand track average factor growth, is retained for structural-change experiments and is described in the subsections that follow.

2.11.2 Capital accumulation

The aggregate capital stock evolves by the standard perpetual-inventory motion equation (G-1): next period's stock is the depreciated current stock plus current investment,

$$K_{r,t+1} \;=\; (1-\delta)\,K_{r,t} + I_{r,t}, \tag{G-1}$$

where current investment $I_{r,t}$ is the solved investment outlay SI_r of period t. The capital-growth factor applied to the next-period capital endowment is $g^K_{r,t} = K_{r,t+1}/K_{r,t}$. The stock tracker is initialised so that the benchmark is stationary: $K_{r,0} = \bar{I}_r/\delta$, i.e. benchmark investment exactly replaces benchmark depreciation, so a no-growth, no-shock run holds the capital stock constant. "Endogenous capital" is the accumulation rule used under the unbalanced mode (`balanced=false`); a further option there grows capital at a fixed exogenous rate g^K. Under the default balanced-growth baseline (Section 2.11.1) the capital endowment instead grows with the common anchor factor (G-0), and the multi-channel capital-damage multiplier (A-4) acts on top of it.

2.11.3 Labour supply and productivity

Labour supply grows by skill: the unskilled and skilled endowments grow at g_{lu} and g_{ls} respectively (defaults $g_{lu} = g_L$, $g_{ls} = g_L + 0.005$, so skilled labour grows slightly faster, reflecting rising educational attainment). Labour-augmenting (total-factor) productivity grows at g_{tfp} (default 0.012). The combined growth factor applied to a labour endowment between periods (G-2) multiplies population growth by productivity growth:

$$g^L_{r,t} \;=\; (1+g_{l\bullet})\,(1+g_{tfp}), \qquad l\bullet \in \{lu, ls\}. \tag{G-2}$$

Capital is not scaled by the TFP factor (capital growth is governed by accumulation, G-1), so the productivity term is labour-augmenting in the Harrod-neutral sense.

2.11.4 Autonomous energy-efficiency improvement

Autonomous energy-efficiency improvement (AEEI) lowers the energy intensity of production over time independently of price effects. Between periods the benchmark intermediate-use coefficients of the emitting commodities (those with a nonzero CO_2 intensity) are scaled down by the AEEI rate (G-3):

$$\bar{Z}^{\,t+1}_{r,i,a} \;=\; (1-\mathrm{aeei})\,\bar{Z}^{\,t}_{r,i,a}, \qquad i \in \{\mathrm{COAL, OIL, GAS, ELYFF}\}, \tag{G-3}$$

with default aeei $= 0.01$ (a 1%/year fall in energy intensity). AEEI is the channel through which emissions can decline even as output grows: efficiency gains outpace scale.

2.11.5 The damage feedback

When the climate-damage feedback is active, the next-period factor endowments are additionally scaled by the period's damage factor $DAMAGE'$ from (Cl-7):

$$\bar{F}^{\,t+1}_{r,f,a} \;=\; \bar{F}^{\,t}_{r,f,a}\cdot g_{r,f,t}\cdot DAMAGE', \tag{G-4}$$

where $g_{r,f,t}$ is the factor-specific growth factor (the capital-accumulation factor for f = CAP, the labour growth factor (G-2) for the labour factors). With the feedback off, $DAMAGE'$ is replaced by 1. This uniform feedback is a single, undifferentiated scalar acting on all factors at once; the multi-channel extension of the next subsection replaces it with damage that is disaggregated by transmission channel and can be offset by adaptation.

2.11.6 Multi-channel climate damage and the adaptation extension

The uniform feedback (G-4) is adequate for studying mitigation but too coarse for adaptation analysis, where the policy question is precisely *which* channel of damage a given measure addresses. CDCGE therefore carries an additive multi-channel damage–adaptation extension to `run_recursive`, activated by the keyword `adaptation=true` and otherwise a no-op (so every existing run is unaffected). It implements the terms-of-reference equations $A_{ag} = A_0(1-D+\varphi)$, $K_{t+1} = (1-\delta-D_K+\varphi_K)K_t + I_t$ and $L_{\text{eff}} = L(1-D_L+\varphi_L)$ as channel-specific multipliers.

Channel damage. The DICE module returns the period's global mean warming $T_t = TATM_t$ (Cl-5). For each channel $c \in \{\text{ag, water, cap, lab}\}$ the damage fraction is quadratic in warming and capped,

$$D_t^c \;=\; \min\bigl(\alpha_c T_t^2,\ \overline{D}\bigr), \qquad \overline{D} = \texttt{damage\_cap} = 0.9, \tag{A-1}$$

with channel intensities α_c set by the keywords `dam_ag` (default 0.0040), `dam_wat` (0.0030), `dam_cap` (0.0015) and `dam_lab` (0.0020). Agriculture is the most warming-sensitive channel and capital the least, reflecting the empirical literature.

Adaptation as damage offset. Adaptation neutralises a share $a_c \in [0,1]$ of each channel's damage. That share is split into an *autonomous* (market) component and a *planned* (government) component, supplied as per-channel dictionaries `phi_auto` and `phi_plan` and summed (and clamped) channel by channel,

$$a_c = \text{clamp}\bigl(\varphi_c^{\text{auto}} + \varphi_c^{\text{plan}},\, 0,\, 1\bigr), \qquad m_t^c \;=\; 1 - D_t^c\,(1-a_c) \;=\; 1 - D_t^c + \varphi_t^c, \tag{A-2}$$

where $\varphi_t^c = D_t^c a_c$ is the adapted-away damage. The *effective* multiplier m_t^c is exactly the $1-D+\varphi$ form of the terms of reference: at $a_c = 0$ it is the unmitigated damage $1-D_t^c$; at $a_c = 1$ adaptation fully neutralises the channel ($m_t^c = 1$).

Transmission to the economy. Each multiplier enters the model through the lever that represents its channel:

- **Agriculture and water** act as a Hicks-neutral productivity lever on the next period's solve (the `prod` dictionary). Crops carry both the heat and the water stress, livestock the heat stress, and hydropower-bearing clean electricity the water stress:

$$\lambda_{\text{AGR}}^{t+1} = m_t^{\text{ag}}\, m_t^{\text{wat}}, \quad \lambda_{\text{LIVE}}^{t+1} = m_t^{\text{ag}}, \quad \lambda_{\text{ELYCL}}^{t+1} = m_t^{\text{wat}}. \tag{A-3}$$

  These multiply the period's productivity lever (`merge(*, prod_t, adapt_prod)`), so a value below one is a productivity loss. The agriculture/water hit is applied with a one-period lag, consistent with the recursion's information structure.

- **Capital** scales the carried-forward capital endowment, the discrete analogue of $K_{t+1} = (1-\delta-D_K+\varphi_K)K_t + I_t$:

$$\bar{F}_{r,\text{CAP},a}^{\,t+1} \;=\; \bar{F}_{r,\text{CAP},a}^{\,t} \cdot g_{r,\text{CAP},t} \cdot m_t^{\text{cap}}. \tag{A-4}$$

- **Labour/health** scales the effective labour supply, $L_{\text{eff}} = L(1-D_L+\varphi_L)$:

$$\bar{F}_{r,\text{LAB},a}^{\,t+1} \;=\; \bar{F}_{r,\text{LAB},a}^{\,t} \cdot g_{r,\text{LAB},t} \cdot m_t^{\text{lab}}, \qquad \text{LAB} \in \{\text{LAB\_UNSK, LAB\_SK}\}. \tag{A-5}$$

When the extension is active the channel multipliers (A-3)–(A-5) replace the uniform feedback (G-4): the scalar $DAMAGE'$ is set to 1 so damage is applied once, through the channels, not twice.

The cost of planned adaptation. Autonomous adaptation is costless to the public budget; planned adaptation is financed by diverting a share of investment, so it carries a genuine opportunity cost. The next period's autonomous investment demand is scaled by

$$\text{cost\_fac} \;=\; 1 - \text{clamp}\Big(\texttt{adapt\_cost\_share} \cdot \textstyle\sum_c \varphi_c^{\text{plan}},\; 0,\; 0.5\Big), \tag{A-6}$$

applied to the investment anchors `INV0` and `I0`. This is what makes the autonomous-versus-planned comparison (Section 6.6 of the country reports) economically meaningful: planned adaptation buys more damage offset but at the price of lower near-term capital formation.

Diagnostics. The extension writes the effective damage fraction of each channel, $D_t^c(1-a_c) = 1 - m_t^c$, as the output rows `Dmg_ag`, `Dmg_wat`, `Dmg_cap` and `Dmg_lab`, so the realised (post-adaptation) damage path of every channel can be charted directly. The default channel intensities are illustrative parameters spanning a plausible range; the analytical content is the *comparative* economics of the channels and of the autonomous, planned and disaster-risk-reduction packages, not the absolute damage levels.

2.11.7 The recursion in summary

The per-period loop is: (i) solve the static equilibrium for the current calibration, warm-starting from the previous period's solution (essential for robust convergence under large shocks — a homotopy); (ii) record macro and extended results (factor income, household income, investment, capital, emissions, and the climate-status reporting variables below); (iii) step the climate state with the period's global emissions; (iv) compute the multi-channel damage and adaptation multipliers (A-1)–(A-6) and invoke the optional per-period hook; (v) build the next-period calibration by growing the factor endowments (capital by accumulation, labour by (G-2), scaled either by the uniform damage (G-4) or by the channel multipliers (A-4)–(A-5)), diverting investment for planned adaptation (A-6), and applying AEEI (G-3); (vi) repeat. The warm-start is what makes the recursion robust: each period starts from a solved point close to the new equilibrium, so PATH converges in a handful of iterations even when a carbon tax or a damage shock has moved the economy far from the benchmark.

2.11.8 Extended outcome reporting and the streaming hook

To support the country climate-status applications, `run_recursive` emits, in addition to the macro aggregates, a panel of per-period, per-region reporting variables read directly from the solved model: `GDPMP` (GDP at market prices), `Welf` (real-consumption welfare), `Emi` (regional CO_2), `YG` (government revenue), `GovSpend`, `TradeBal`, `ExportsTot` and `ImportsTot`; the sectoral vectors `XP[·]` (output) and `VA[·]` (value added); the factor vectors `WF[·]` (wages), `EMP[·]` (employment) and `YF[·]` (factor income); and energy demand by fuel `XA[·]`. Three composite indicators are defined for the adaptation analysis:

$$\text{RuralIncome} = VA_{\text{AGR}} + VA_{\text{LIVE}}, \quad \text{FoodPrice} = PA_{\text{AGR}}, \quad \text{FoodSecIndex} = \frac{XP_{\text{AGR}} + XP_{\text{LIVE}}}{PA_{\text{AGR}}}, \tag{A-7}$$

i.e. the returns to rural factors, the food price, and real food availability per unit food price. A per-period `status` flag (1 if the step reached LOCALLY_SOLVED) is also recorded, so non-converged periods can be masked in downstream reporting. All of this extraction is purely additive — it only reads the solved values — so it does not alter the equilibrium.

The optional keyword `on_period` accepts a callback `(t, status, model, climate)` that fires after each annual solve. It lets a caller stream the solution path live (printing or plotting each year as it lands) without waiting for the full horizon, and is used by the live-path scripts; when omitted it is a no-op.

2.12 The complete equilibrium system

Collecting the blocks, a CDCGE equilibrium is a vector of prices ($PX, PND1, PVA, PKEF, PKS, PEN, PELY$ $PCely, PCnely, PColg, PNUM$) and quantities ($XP, ND1, VA, KEF, KS, EN, XELY, NELY, OLG, XN, XI$ $XAc, XAg, XAi, XCnrg, XCely, XCnely, XColg, Ysup$) together with the income, fiscal, capital, emissions and macro variables ($YF, YH, YD, Sh, Sg, SI, Ks, DeprY, YG, YGOV, Emi, EmiGbl,$ $GDPMP, Welf$) such that:

1. every producer earns zero pure profit and minimises cost given the nested technology (P-1–P-13);
2. the household maximises Stone–Geary utility subject to its budget and the energy nest (D-1–D-7), and government and investment demand exhaust their budgets (D-8–D-9);
3. every commodity market clears (T-4), with Armington/CET demand and supply (T-1–T-3, T-5–T-10);
4. every factor market clears (M-fac);
5. each agent's income and saving satisfy the accounting identities (Y-1–Y-16);
6. the numéraire is fixed (M-1) and net foreign saving is at its exogenous level;
7. emissions satisfy the accounting identities (E-1–E-2).

Each of these conditions is registered as one complementarity pair, and the total count equals the number of variables, so the problem is square. PATH solves it; at the benchmark the residual is ≈ 0 and the data are reproduced. The recursive dynamics (G-0–G-4), the multi-channel damage–adaptation extension (A-1–A-7) and the climate step (Cl-1–Cl-7) then advance the system between periods. This completes the structural specification; the next chapter shows how the benchmark levels and shares ($\bar{X}, \bar{Z}, \bar{F}, \bar{s}^d, \dots$) that appear throughout are recovered from the balanced SAM.

Chapter 3

The MAMS human-development module

The equation system of Chapter 2 is a pure economy: it prices goods and factors, allocates production and trade, and closes the macro accounts. It says nothing about whether children finish school, whether households drink safe water, or whether a clinic has electricity. Yet these are exactly the outcomes a development-policy question is about, and they are not independent of the economy: they are *bought* out of the government budget, they respond to household income, and they feed back into the economy through the size and the quality of the labour force.

CDCGE therefore carries an optional **human-development module**, a re-implementation of the MAMS "MDG module" of Lofgren, Cicowiez and Díaz-Bonilla — in its SDG variant — on top of the square-MCP core. MAMS (*Maquette for MDG Simulations*) is the World Bank's standard country CGE for development-strategy analysis, and its distinctive contribution is precisely this layer: government spending by function drives real service delivery, real service delivery drives education and health outcomes through logistic behavioural functions, and those outcomes feed back into labour supply and labour productivity. The module is activated with `human_dev=true` and assembled by six blocks — `InfrastructureBlock`, `EnergySpendingBlock`, `WaterBlock`, `SanitationBlock`, `HealthBlock` and `EducationBlock` — on the shared scaffolding in `src/HumanDevelopment.jl`. Its equations are numbered (H-1)–(H-26) below.

3.1 Design: a triangular tail on a square core

The MAMS coupling between the economy and human development is genuinely two-way: service delivery improves education, education enlarges the skilled labour force, and a larger skilled labour force changes the economy that pays for the services. Solving that simultaneously would put a large, highly non-linear, sigmoid-shaped system *inside* the equilibrium fixed point, and would put at risk the numerical reliability on which the core solve depends.

CDCGE resolves this the way MAMS itself does — by splitting the loop across time. *Within* a period, the human-development variables are computed *from* the core solution (solved prices, wages, government spending and consumption) and do not feed back into it: the module is a block-recursive, or triangular, tail hanging off the square core. *Between* periods the loop is closed: graduation flows augment the skill-specific labour supply and health status raises labour productivity, so the next period's core economy is the one this period's human development produced. The consequences are worth stating explicitly, because they are what make the module safe to switch on:

- the core equilibrium is numerically undisturbed — adding the tail cannot turn a solve that converged into one that fails;
- the module is square in its own right (one complementarity pair per human-development variable), so the whole model stays square;

- every determinant enters as a *ratio to its base year*, so at the benchmark every ratio is 1, every intermediate aggregate is 1, every logistic returns its base value, and the benchmark is reproduced exactly;
- with `human_dev=false` every human-development variable is pinned to its base level and the model is numerically identical to the pure-CGE build of Chapter 2.

The last two points are the same fixed-point property that governs the rest of the model (Section 4.6), extended to the development outcomes.

3.2 Sets

The module adds four sets to those of Section 2.1:

$$\begin{aligned} c \in \mathcal{C}^{edu} &= \{\text{EDUP}, \text{EDUS}, \text{EDUT}\} && \text{education cycles: primary, secondary, tertiary} \\ m \in \mathcal{M} &= \{\text{ROADS}, \text{RAIL}, \text{WATTR}\} && \text{transport-infrastructure modes} \\ s \in \mathcal{S} &= \{\text{SDG3}, \text{SDG6W}, \text{SDG6S}\} && \text{standard SDG indicators} \end{aligned}$$

together with the set of government budget functions

$$gf \;\in\; \mathcal{G} \;=\; \mathcal{C}^{edu} \cup \{\text{HLTH}, \text{WATER}, \text{SANIT}, \text{ENERGY}\} \cup \mathcal{M} \cup \{\text{PADM}\}.$$

$\mathcal{G}$ is the government's functional classification: the three education cycles, health, water, sanitation, energy, the three transport modes, and `PADM` — public administration and defence, the residual non-development function that absorbs any reallocation. The outcomes map to Sustainable Development Goals as in Table 3.1.

Table 3.1: Human-development outcomes and their Sustainable Development Goals.

Outcome	**Variable**	**SDG**	**Producing block**
Primary completion rate	$SDG4_r$	SDG 4 (Education)	`EducationBlock`
Health status	$SDGVAL_{r,\text{SDG3}}$	SDG 3 (Health)	`HealthBlock`
Safe-water access	$SDGVAL_{r,\text{SDG6W}}$	SDG 6.1 (Water)	`WaterBlock`
Sanitation access	$SDGVAL_{r,\text{SDG6S}}$	SDG 6.2 (Sanitation)	`SanitationBlock`
Energy access	$ENERGIDX_r$	SDG 7 (Energy)	`EnergySpendingBlock`
Transport-infra. access	$INFRIDX_r$	SDG 9 (Infrastructure)	`InfrastructureBlock`

3.3 Government expenditure by function

In the core model (D-8) government demand is a single Cobb–Douglas basket bought out of a nominal envelope $\overline{GEXP}_r$. The human-development module decomposes that envelope by *function* (MAMS eq. 41), so that education and health become explicit line items of the fiscal system rather than an anonymous share of a basket. Let $\overline{fsh}_{r,gf}$ be the base budget share of function gf, with $\sum_{gf\in\mathcal{G}} \overline{fsh}_{r,gf} = 1$. Nominal spending by function (H-1), the service-delivery price (H-2) and real service delivery (H-3) are

$$\begin{aligned} GHD_{r,gf} &= \overline{fsh}_{r,gf}\,\overline{GEXP}_r\,PNUM && \perp\; GHD_{r,gf} && \text{(H-1)} \\ PHD_{r,gf} &= \sum_i \bar{g}^{sh}_{r,i}\,PA_{r,i} && \perp\; PHD_{r,gf} && \text{(H-2)} \\ QHD_{r,gf}\,PHD_{r,gf} &= GHD_{r,gf} && \perp\; QHD_{r,gf} && \text{(H-3)} \end{aligned}$$

Every function buys the same government commodity basket $\bar{g}^{sh}_{r,i}$, so its cost index (H-2) is the common basket price, and (H-3) deflates nominal spending into a real service volume. This is deliberately the *minimal* functional disaggregation the data can support: a GTAP-based SAM records one government column, not one per ministry, so a function-specific input mix would be invented data rather than measured data. What the module does claim — and all it needs — is that spending more on a function buys proportionally more of that service in real terms, which is what (H-3) says.

Government commodity demand is then driven by the sum of the function lines rather than by the envelope directly (H-4), replacing (D-8):

$$PA_{r,i}\, XAg_{r,i} \;=\; \bar{g}^{sh}_{r,i} \sum_{gf\in\mathcal{G}} GHD_{r,gf} \qquad \perp\; XAg_{r,i}. \tag{H-4}$$

Because the shares sum to one, $\sum_{gf} GHD_{r,gf} = \overline{GEXP}_r\, PNUM$ identically, so (H-4) is numerically the same equation as (D-8): the commodity market, the fiscal balance and the benchmark are all preserved. The decomposition adds information without perturbing the economy — which is precisely what allows the base year to remain an exact fixed point.

3.4 Consumption per capita and infrastructure access

The `InfrastructureBlock` runs first among the human-development blocks, because it depends only on the core economy, and it owns the two income determinants that every other block shares. With $\bar{p}_r$ the base population scale and π_r the cumulative population ratio at the current period ($\pi_r = 1$ in the base year; see Section 3.8), real household consumption per capita (MAMS eq. 69) and gross national expenditure per capita are

$$QHPC_r \;=\; \frac{Welf_r}{\bar{p}_r\, \pi_r} \qquad \perp\; QHPC_r \tag{H-5}$$

$$GNEPC_r \;=\; \frac{GDPMP_r}{\bar{p}_r\, \pi_r} \qquad \perp\; GNEPC_r \tag{H-6}$$

where $Welf_r$ is the real consumption volume (M-4) and $GDPMP_r$ expenditure GDP (M-3). $QHPC$ is the household-income determinant of every outcome; $GNEPC$ is the broader national-income determinant that the SDG variant of MAMS adds.

MAMS carries a single public-infrastructure stock. CDCGE disaggregates it into the three transport modes of $\mathcal{M}$, because the transport satellite of the EDIS system reports mode by mode. Each mode's access index is its per-capita real service delivery relative to base (H-7), and the three are combined Cobb–Douglas into the aggregate index (H-8):

$$MIDX_{r,m} \;=\; \frac{QHD_{r,m}/\overline{QHD}_{r,m}}{\pi_r} \qquad \perp\; MIDX_{r,m}, \quad m\in\mathcal{M} \tag{H-7}$$

$$INFRIDX_r \;=\; \prod_{m\in\mathcal{M}} MIDX_{r,m}^{w_m}, \qquad \sum_m w_m = 1 \qquad \perp\; INFRIDX_r \tag{H-8}$$

$MIDX_{r,m}$ is $ROADIDX$, $RAILIDX$ and $WATTRIDX$ in the source. The weights w_m (`infra_w_roads`, `infra_w_rail`, `infra_w_wattr`; defaults 0.5, 0.25, 0.25) are renormalised to sum to one, so $INFRIDX_r = 1$ at base whatever they are set to. A mode with no benchmark spending has its index pinned to 1 and drops out of the product.

3.5 Energy access

Energy access is the one human-development determinant that is not primarily a budget line: a school has electricity because the power sector generates it. The `EnergySpendingBlock` therefore wires the energy-access index directly to the model's *electricity sector* — the same generation commodities $e \in \mathcal{E}^{ely} = \text{ELYFF} \cup \text{ELYCL}$ that the production and supply blocks build — with government energy spending (electrification programmes) as a second, multiplicative factor:

$$ENERGIDX_r \;=\; \left(\frac{\sum_{e\in\mathcal{E}^{ely}} XP_{r,e}}{\sum_{e\in\mathcal{E}^{ely}} \bar{X}_{r,e}} \cdot \frac{1}{\pi_r} \right)^{\phi^{el}} \left(\frac{QHD_{r,\text{ENERGY}}/\overline{QHD}_{r,\text{ENERGY}}}{\pi_r} \right)^{\phi^{eg}} \quad \perp \; ENERGIDX_r. \tag{H-9}$$

This closes a genuine energy–development linkage that a budget-only formulation misses: a carbon price that reshapes the generation mix, or an investment programme that expands it, moves energy access, which moves schooling, health, water treatment and the cold chain. If the build carries no electricity commodity the first factor drops out and access is driven by government spending alone; if there is neither, $ENERGIDX_r$ is pinned to 1.

3.6 The water, sanitation and health indicators

The three standard SDG indicators share one functional form, the MAMS MDG specification (eqs. 80–81). Each indicator is a *logistic* function of an intermediate determinant aggregate $ZSDG$, and each $ZSDG$ is a *constant-elasticity* (Cobb–Douglas in logs) product of determinants, every one of them a ratio to its base year. Writing $\hat{x} \equiv x/\bar{x}$ for such a ratio, and $svc_{r,s}$ for the per-capita real service delivery of the function that produces indicator s,

$$svc_{r,s} \;=\; \frac{QHD_{r,gf(s)}/\overline{QHD}_{r,gf(s)}}{\pi_r}, \qquad \begin{array}{r} gf(\text{SDG3}) = \text{HLTH}, \\ gf(\text{SDG6W}) = \text{WATER}, \\ gf(\text{SDG6S}) = \text{SANIT}, \end{array} \tag{3.1}$$

the three determinant aggregates are (H-10)–(H-12), each complementary to the variable on its own left-hand side:

$$ZSDG_{r,\text{SDG6W}} = svc_{r,\text{SDG6W}}^{\phi^w_{srv}} \, \widehat{QHPC}_r^{\phi^w_{cns}} \, \widehat{GNEPC}_r^{\phi^w_{gne}} \, INFRIDX_r^{\phi^w_{inf}} \, ENERGIDX_r^{\phi^w_{eng}} \tag{H-10}$$

$$ZSDG_{r,\text{SDG6S}} = svc_{r,\text{SDG6S}}^{\phi^s_{srv}} \, \widehat{QHPC}_r^{\phi^s_{cns}} \, \widehat{GNEPC}_r^{\phi^s_{gne}} \, INFRIDX_r^{\phi^s_{inf}} \tag{H-11}$$

$$\begin{aligned} ZSDG_{r,\text{SDG3}} = {} & svc_{r,\text{SDG3}}^{\phi^h_{srv}} \, \widehat{SDGVAL}_{r,\text{SDG6W}}^{\phi^h_{wat}} \, \widehat{SDGVAL}_{r,\text{SDG6S}}^{\phi^h_{san}} \, \widehat{QHPC}_r^{\phi^h_{cns}} \\ & \times \, \widehat{GNEPC}_r^{\phi^h_{gne}} \, INFRIDX_r^{\phi^h_{inf}} \, ENERGIDX_r^{\phi^h_{eng}} \end{aligned} \tag{H-12}$$

and each indicator follows from its logistic (H-13):

$$SDGVAL_{r,s} \;=\; ext_s + \frac{\alpha_{r,s}}{1 + \exp(\gamma_{r,s} + \beta_s \, ZSDG_{r,s})} \qquad \perp \; SDGVAL_{r,s}, \qquad s \in \mathcal{S}. \tag{H-13}$$

Two features of this specification deserve comment. First, the *cross-SDG* terms in (H-12): water and sanitation enter health, but health does not enter water or sanitation. That is an empirical claim — waterborne disease is a leading cause of child mortality — and it is also what keeps the tail acyclic, so the blocks can be built in the fixed order water → sanitation → health → education. Second, the logistic is what encodes *diminishing returns to service delivery*: a country at 55 % sanitation coverage gains far more from a given spending increase than one at 95 %, and no amount of spending pushes an indicator past its ceiling ext_s (100 by default). A constant-elasticity specification alone would imply unbounded, scale-free improvement, which is exactly the error the MAMS sigmoid was introduced to avoid.

The amplitude α and the intercept γ are not free parameters: they are back-solved so that the sigmoid reproduces the base-year outcome at the base-year determinant and has its inflection point at ιZ_0 (Appendix F). Only the slope β_s is exogenous, and it is the natural per-country calibration handle — it sets how elastically service delivery moves the indicator.

3.7 Education by cycle

Education is the richest part of the module, because the outcome is not a single coverage rate but a *cohort passing through a system.* MAMS models grade-by-grade stocks and flows; CDCGE keeps the same behavioural core and reduces the accounting to a base-normalised cohort chain.

Educational quality. Quality (MAMS eq. 70) is real service delivery per student, relative to base — so a cycle whose enrolment grows faster than its budget suffers a quality dilution:

$$EDUQUAL_{r,c} = \frac{QHD_{r,c}/\overline{QHD}_{r,c}}{QENR_{r,c}/\overline{QENR}_{r,c}} \qquad \perp\ EDUQUAL_{r,c}. \tag{H-14}$$

The determinant aggregate. As for the SDGs, a constant-elasticity product of ratios (MAMS eq. 75), now including the *return to schooling* — the skilled/unskilled wage premium the core model prices — and *child health*, the SDG3 indicator the health block has just produced:

$$\begin{aligned} ZEDU_{r,c} &= EDUQUAL_{r,c}^{\phi^e_{qal}} \left(\frac{WF_{r,\text{LAB\_SK}}}{WF_{r,\text{LAB\_UNSK}}}\right)^{\phi^e_{wag}} \widehat{SDGVAL}_{r,\text{SDG3}}^{\phi^e_{hlt}}\ \widehat{QHPC}_r^{\phi^e_{cns}} \\ &\times \widehat{GNEPC}_r^{\phi^e_{gne}}\ INFRIDX_r^{\phi^e_{inf}}\ ENERGIDX_r^{\phi^e_{eng}} \qquad \perp\ ZEDU_{r,c}. \end{aligned} \tag{H-15}$$

The wage-premium term is what makes schooling an *investment* decision in this model rather than a pure consumption good: when the core economy raises the skill premium — because a policy shifted production toward skill-intensive sectors, say — households keep children in school longer, the mechanism the returns-to-schooling literature documents. Benchmark prices are all unity, so the premium is 1 at base and the term is neutral there.

Behaviour. The three student-behaviour shares are logistic in the determinant aggregate (MAMS eq. 74) — grade-1 net intake driven by primary conditions, promotion/graduation and continuation to the next cycle by conditions in the cycle itself:

$$SHENTRY_r = ext^{en} + \frac{\alpha^{en}_r}{1+\exp(\gamma^{en}_r + \beta^{en} ZEDU_{r,\text{EDUP}})} \qquad \perp\ SHENTRY_r \tag{H-16}$$

$$SHPASS_{r,c} = ext^{pa} + \frac{\alpha^{pa}_{r,c}}{1+\exp(\gamma^{pa}_{r,c} + \beta^{pa} ZEDU_{r,c})} \qquad \perp\ SHPASS_{r,c} \tag{H-17}$$

$$SHCONT_{r,c} = ext^{co} + \frac{\alpha^{co}_{r,c}}{1+\exp(\gamma^{co}_{r,c} + \beta^{co} ZEDU_{r,c})} \qquad \perp\ SHCONT_{r,c} \tag{H-18}$$

The terminal cycle has no continuation, so $SHCONT_{r,\text{EDUT}}$ is pinned.

Cohort accounting. Improved behaviour propagates down the cycles as an *intake index* — the ratio of the cohort now arriving in a cycle to the cohort that arrived in the base year (a reduced form of MAMS eqs. 71–73):

$$\begin{aligned} II_{r,\text{EDUP}} &= \frac{SHENTRY_r}{\overline{SHENTRY}_r}, \qquad II_{r,\text{EDUS}} = II_{r,\text{EDUP}} \frac{SHPASS_{r,\text{EDUP}}}{\overline{SHPASS}_{r,\text{EDUP}}} \frac{SHCONT_{r,\text{EDUP}}}{\overline{SHCONT}_{r,\text{EDUP}}}, \\ II_{r,\text{EDUT}} &= II_{r,\text{EDUS}} \frac{SHPASS_{r,\text{EDUS}}}{\overline{SHPASS}_{r,\text{EDUS}}} \frac{SHCONT_{r,\text{EDUS}}}{\overline{SHCONT}_{r,\text{EDUS}}} \end{aligned} \tag{H-19}$$

Enrolment and annual graduates then scale off their benchmarks,

$$QENR_{r,c} = \overline{QENR}_{r,c}\, II_{r,c} \qquad \perp\ QENR_{r,c} \tag{H-20}$$

$$GRAD_{r,c} = \overline{GRAD}_{r,c}\; II_{r,c}\, \frac{SHPASS_{r,c}}{\overline{SHPASS}_{r,c}} \qquad \perp\; GRAD_{r,c} \tag{H-21}$$

and the primary-completion indicator (MAMS eq. 77, reduced cohort form) is the product of intake and primary promotion:

$$SDG4_r \;=\; 100\, SHENTRY_r\, SHPASS_{r,\mathrm{EDUP}} \qquad \perp\; SDG4_r. \tag{H-22}$$

Equations (H-14)–(H-22) contain a genuine simultaneity — quality (H-14) depends on enrolment (H-20), which depends on behaviour (H-16)–(H-18), which depends on quality — and it is solved as a fixed point together with the rest of the tail, not by iteration. The congestion effect this captures is real and policy-relevant: a campaign that raises intake without raising the budget dilutes quality, which lowers promotion, which partly undoes the gain.

3.8 Between-period feedbacks

The MAMS two-way coupling is closed recursively, in `run_recursive`. Two multipliers are computed from the solved outcomes at the end of each period and applied to the next period's factor supply. Skill-specific labour supply grows with graduation (MAMS eq. 79) — secondary and tertiary graduates feed the skilled pool, primary graduates the unskilled pool:

$$\mu^{lab}_{r,\mathrm{LAB\_SK}} = \left(\frac{GRAD_{r,\mathrm{EDUS}} + GRAD_{r,\mathrm{EDUT}}}{\overline{GRAD}_{r,\mathrm{EDUS}} + \overline{GRAD}_{r,\mathrm{EDUT}}}\right)^{\theta^{lab}}, \qquad \mu^{lab}_{r,\mathrm{LAB\_UNSK}} = \left(\frac{GRAD_{r,\mathrm{EDUP}}}{\overline{GRAD}_{r,\mathrm{EDUP}}}\right)^{\theta^{lab}} \tag{H-23}$$

and labour productivity rises with health status (the MAMS `fprd` channel):

$$\mu^{hlth}_r \;=\; \left(\frac{SDGVAL_{r,\mathrm{SDG3}}}{\overline{SDGVAL}_{r,\mathrm{SDG3}}}\right)^{\theta^{hlt}}. \tag{H-24}$$

Both are *level* multipliers relative to the base year, so they are applied incrementally, μ_t/μ_{t-1}, on top of the balanced-growth labour scaling of (G-2); the cumulative effect is then exactly μ_t and there is no double counting. The next period's labour endowment is therefore

$$\bar{F}^{\,t+1}_{r,f,i} \;=\; \bar{F}^{\,t}_{r,f,i}\,(1+g^{eff}_r)\,\frac{\mu^{lab,t}_{r,f}}{\mu^{lab,t-1}_{r,f}}\,\frac{\mu^{hlth,t}_r}{\mu^{hlth,t-1}_r}, \qquad f \in \{\mathrm{LAB\_SK}, \mathrm{LAB\_UNSK}\}. \tag{H-25}$$

Finally, the population scale used in the per-capita determinants (H-5)–(H-9) accumulates with population growth,

$$\pi^{t+1}_r \;=\; \pi^t_r\,(1+g^{pop}_r), \qquad \pi^0_r = 1, \tag{H-26}$$

so a rising population dilutes per-capita service delivery unless spending keeps pace — the demographic pressure that dominates SDG attainment in fast-growing economies. At $\mu \equiv 1$ and $\pi \equiv 1$ — the base year, or any scenario held at base values — the recursion is exactly the baseline of Section 2.11, so switching the module on does not move the baseline path.

3.9 Elasticities and base-year parameters

As elsewhere in CDCGE, levels and shares are calibrated and only elasticities are assumed. The human-development elasticities live in `ELAST_DEFAULTS` alongside the production and trade elasticities (Table 3.2); the base-year levels and shares are carried in `HDParams` (Table 3.3).

Because every determinant is a ratio, the absolute enrolment and population scales are innocuous and are normalised; `default_hd_params(cal)` builds a plausible enrolment pyramid and SDG starting points that can be overridden country by country. For African applications that is not necessary — the World Bank panel supplies the observed values.

Table 3.2: Human-development elasticities (`ELAST_DEFAULTS`).

Symbol	Meaning	Default
$\beta^{en}, \beta^{pa}, \beta^{co}$	logistic slopes: intake, promotion, continuation	2.0
$\beta_{\text{SDG3}}, \beta_{\text{SDG6W}}, \beta_{\text{SDG6S}}$	logistic slopes: health, water, sanitation	1.5
ι	inflection-point multiplier (base year at ιZ_0)	1.0
$w_{\text{ROADS}}, w_{\text{RAIL}}, w_{\text{WATTR}}$	infrastructure aggregation weights	0.50, 0.25, 0.25
ϕ^e_{qal}	education: quality (service per student)	0.50
ϕ^e_{wag}	education: skill wage premium (return to schooling)	0.30
ϕ^e_{hlt}	education: child health	0.20
$\phi^e_{cns}, \phi^e_{gne}$	education: consumption p.c., GNE p.c.	0.40, 0.10
$\phi^e_{inf}, \phi^e_{eng}$	education: infrastructure, energy access	0.10, 0.10
ϕ^h_{srv}	health: per-capita service delivery	0.50
$\phi^h_{wat}, \phi^h_{san}$	health: water, sanitation (cross-SDG)	0.20, 0.15
$\phi^h_{cns}, \phi^h_{gne}$	health: consumption p.c., GNE p.c.	0.30, 0.10
$\phi^h_{inf}, \phi^h_{eng}$	health: infrastructure, energy access	0.15, 0.10
$\phi^w_{srv}, \phi^s_{srv}$	water, sanitation: per-capita service delivery	0.50
$\phi^w_{cns}, \phi^s_{cns}$	water, sanitation: consumption p.c.	0.30
$\phi^w_{gne}, \phi^s_{gne}$	water, sanitation: GNE p.c.	0.10
$\phi^w_{inf}, \phi^s_{inf}$	water, sanitation: infrastructure	0.15
ϕ^w_{eng}	water: energy access (pumping, treatment)	0.10
ϕ^{el}, ϕ^{eg}	energy access: electricity output, government spending	1.0, 0.5
θ^{lab}	skill labour-supply growth w.r.t. graduation	0.60
θ^{hlt}	labour productivity w.r.t. health status	0.15

3.10 Scenario levers

Three constructors move the fiscal mix. All of them leave the base-year references untouched, so the scenario moves the government envelope the model actually uses while solved service delivery QHD rises above the fixed base — which is what improves the outcomes:

- `gov_spending_ratios(hd)` reports the current mix as $\overline{fsh}_{r,gf}\overline{GEXP}_r/\overline{GNE}_r$ — spending on each function as a ratio to GDP.
- `with_gov_spending(cal, hd; education=..., health=..., ...)` enters *exogenous spending levels as ratios to GDP* — the form in which a budget or an MTEF ceiling is actually stated. Total nominal spending becomes the sum of the entered function levels and the split becomes the entered split; both flow through to commodity demand, the fiscal balance and the SDG determinants. Entering the base ratios reproduces the benchmark.
- `with_hd_spending(cal, hd; edu=1.5, health=1.4, watsan=1.3, ...)` scales the mix *multiplicatively*, and optionally the whole envelope (`gov_size`), renormalising over $\mathcal{G}$ so that `PADM` absorbs the reallocation.

```
gov_spending_ratios(hd)                           # base spending/GDP by function
cal2, hd2 = with_gov_spending(cal, hd;            # enter new ratios to GDP
                education=0.065, health=0.035, energy=0.01,
                water=0.006, sanitation=0.006)
m2, _ = solve_cal(cal2; starts=solution_starts(m),  # warm-start large fiscal shifts
                 build_kw=merge(base_kw, (human_dev=true, hd=hd2)))
```

Table 3.3: Base-year human-development parameters (`HDParams`).

Parameter	Meaning
$\overline{GEXP}_r$	base government current expenditure (from the SAM)
$\overline{fsh}_{r,gf}$	base budget share of function gf (summing to one)
$\overline{QHD}_{r,gf}$	base real service delivery, $= \overline{fsh}_{r,gf}\overline{GEXP}_r$
$\overline{Welf}_r, \overline{GNE}_r, \bar{p}_r$	base consumption volume, gross national expenditure, population scale
$\overline{QENR}_{r,c}, \overline{GRAD}_{r,c}$	base enrolment stock and annual graduates by cycle
$\overline{SHENTRY}_r, \overline{SHPASS}_{r,c}, \overline{SHCONT}_{r,c}$	base behaviour shares
$\overline{SDGVAL}_{r,s}$	base SDG indicator levels (0–100)
$ext_\bullet$	logistic ceiling of each behaviour share / indicator

Chapter 4

Calibration

Calibration is the procedure that recovers every level and share parameter of the model from a single balanced benchmark data set, so that the calibrated model reproduces that data set as an equilibrium. CDCGE calibrates *directly from the balanced SAM*: there is no separate parameter file of behavioural levels. Only the substitution and transformation elasticities (Tables 2.2, 2.3, 2.4) and the Frisch parameter use documented literature values; everything else — the technical coefficients, the value shares, the tax rates, the savings rates, the foreign-saving balances — is read off the benchmark. This chapter documents the calibration formulas exactly as implemented in `src/StaticCalibration.jl` (the function `calibrate_sam`).

The guiding principle is *calibration by construction with unit benchmark prices*. All benchmark prices are normalised to 1, so a benchmark value equals the corresponding benchmark quantity, and a value share equals a quantity share. This is why the model can pass benchmark *values* into the CES helper (Section 2.2) and let it form shares internally, and why a no-shock solve reproduces the data: the calibrated coefficients are precisely those that make the benchmark a fixed point.

4.1 Inferring the dimensions

`calibrate_sam` first scans the account labels of the balanced SAM to infer the model dimensions. Region codes and sector codes are read from the `SEC:`r`:`i accounts, and the raw factor codes from the `FAC:`r`:`f accounts. The model factor set is the five GTAP endowments:

$$F = \{\mathrm{LAND},\ \mathrm{LAB\_UNSK},\ \mathrm{LAB\_SK},\ \mathrm{CAP},\ \mathrm{NRS}\},$$

with the one-to-one mapping

$$\mathrm{fmap}(f) = \begin{cases} \mathrm{LAND} & \text{if } f = \mathrm{Land}, \\ \mathrm{LAB\_UNSK} & \text{if } f = \mathrm{UnSkLab}, \\ \mathrm{LAB\_SK} & \text{if } f = \mathrm{SkLab}, \\ \mathrm{CAP} & \text{if } f = \mathrm{Capital}, \\ \mathrm{NRS} & \text{if } f = \mathrm{NatRes}. \end{cases} \tag{Cal-0}$$

That is, the five GTAP primary endowments are mapped one-to-one onto the five model factors. Land is allocated across crop and livestock activities by an adjusted CET (ENVISAGE §3.8.3) and each extraction sector draws on an iso-elastic natural-resource supply curve (ENVISAGE §3.8.4); passing `separate_land_natres=true` keeps `LAND` and `NRS` as distinct factors rather than folding them into capital. The elasticity dictionary is merged from the defaults (`ELAST_DEFAULTS`) with any user overrides.

4.2 Production coefficients

For each region r and sector j the calibration reads the SAM matrix M (the square matrix form of the long SAM, indexed by account) and forms the following. Intermediate use of i by j is the corresponding SAM cell, and the total intermediate bundle is their sum (Cal-1):

$$\bar{Z}_{r,i,j} = M[\text{SEC:}r\text{:}i,\ \text{SEC:}r\text{:}j], \qquad N\bar{D}0_{r,j} = \sum_i \bar{Z}_{r,i,j}. \tag{Cal-1}$$

Factor use folds the six raw components into three (Cal-2):

$$\bar{F}_{r,\text{fmap}(f),j} \mathrel{+}= M[\text{FAC:}r\text{:}f,\ \text{SEC:}r\text{:}j], \qquad V\bar{A}_{r,j} = \sum_f M[\text{FAC:}r\text{:}f,\ \text{SEC:}r\text{:}j]. \tag{Cal-2}$$

Production-tax and indirect-tax payments are read from the `PTAX`/`GOV` and `ITAX` cells (Cal-3):

$$\bar{tp}_{r,j} = M[\text{PTAX:}r,\ \text{SEC:}r\text{:}j] + M[\text{GOV:}r\text{:GOV},\ \text{SEC:}r\text{:}j], \quad \bar{ti}_{r,j} = M[\text{ITAX:}r,\ \text{SEC:}r\text{:}j]. \tag{Cal-3}$$

Gross output is intermediate use plus value added plus taxes (Cal-4):

$$\bar{X}_{r,j} = N\bar{D}0_{r,j} + V\bar{A}_{r,j} + \bar{tp}_{r,j} + \bar{ti}_{r,j}. \tag{Cal-4}$$

The tax rates and Leontief coefficients are then ratios to gross output (Cal-5):

$$\tau^p_{r,j} = \frac{\bar{tp}_{r,j}}{\bar{X}_{r,j}}, \quad \tau^i_{r,j} = \frac{\bar{ti}_{r,j}}{\bar{X}_{r,j}}, \quad \bar{a}^{va}_{r,j} = \frac{V\bar{A}_{r,j}}{\bar{X}_{r,j}}, \quad \bar{a}^{nd1}_{r,j} = \frac{N\bar{D}0_{r,j}}{\bar{X}_{r,j}}. \tag{Cal-5}$$

The intermediate input–output coefficients and the value-added factor shares are (Cal-6):

$$\text{io\_coef}_{r,i,j} = \frac{\bar{Z}_{r,i,j}}{\bar{X}_{r,j}}, \qquad \alpha^{va}_{r,f,j} = \frac{\bar{F}_{r,f,j}}{V\bar{A}_{r,j}}. \tag{Cal-6}$$

These coefficients feed (P-1), (P-3)–(P-6) and the value-added/factor nests (P-7)–(P-9): the Leontief coefficients $\bar{a}^{nd1}, \bar{a}^{va}$ are exactly the top-tier production coefficients, the tax rates enter the zero-profit condition, and the factor shares are the benchmark CES shares. The benchmark bundle values $(V\bar{A}, K\bar{E}F, K\bar{S}, E\bar{N}, \dots)$ used by the energy nests are built in the model builder by re-aggregating $\bar{Z}$ over the energy subsets and $\bar{F}$ over the factors (Section 2.3).

4.3 Final-demand shares

Household, government and investment demand and their budget shares are read from the corresponding final-demand cells (Cal-7):

$$\bar{C}_{r,i} = M[\text{SEC:}r\text{:}i,\ \text{HH:}r], \quad \bar{G}_{r,i} = M[\text{SEC:}r\text{:}i,\ \text{GOV:}r], \quad \bar{I}_{r,i} = M[\text{SEC:}r\text{:}i,\ \text{INV:}r], \tag{Cal-7}$$

with budget shares relative to the agent totals (Cal-8):

$$\bar{s}^c_{r,i} = \frac{\bar{C}_{r,i}}{\sum_k \bar{C}_{r,k}}, \quad \bar{s}^g_{r,i} = \frac{\bar{G}_{r,i}}{\sum_k \bar{G}_{r,k}}, \quad \bar{s}^{inv}_{r,i} = \frac{\bar{I}_{r,i}}{\sum_k \bar{I}_{r,k}}. \tag{Cal-8}$$

Total government expenditure $GE\bar{X}P_r = \sum_i \bar{G}_{r,i}$ and total investment $I\bar{N}V_r = \sum_i \bar{I}_{r,i}$ are stored for the closure. The government and investment shares $\bar{s}^g, \bar{s}^{inv}$ are the Cobb–Douglas shares in (D-8)–(D-9); the consumption levels $\bar{C}_{r,i}$ are the data used to calibrate the LES marginal budget shares and subsistence quantities (Section 2.4, $\beta_i = \bar{C}_{r,i}/\bar{C}^{tot}_r$, $\gamma_i = \bar{C}_{r,i}(1 - 1/|\phi|)$).

4.4 Trade shares

For each region and commodity, exports and imports are reconstructed from the bilateral cells of the SAM. Exports to partner r' are the cell from r's sector account to r''s sector account, plus any flow to the single-account RoW; imports are the transpose (Cal-9):

$$\bar{XW}_{r,r',i} = M[\text{SEC:}r\text{:}i,\ \text{SEC:}r'\text{:}i], \qquad \text{imp\_src}_{r,r',i} = M[\text{SEC:}r'\text{:}i,\ \text{SEC:}r\text{:}i], \tag{Cal-9}$$

with total exports $\bar{E}_{r,i} = \sum_{r'\neq r} \bar{XW}_{r,r',i} + M[\text{SEC}, \text{ROW}]$ and total imports $\bar{M}_{r,i} = \sum_{r'\neq r} \text{imp\_src}_{r,r',i} + M[\text{ROW}, \text{SEC}]$. The Armington and CET shares follow. Let domestic output net of exports be $\bar{d}_{r,i} = \max(\bar{X}_{r,i} - \bar{E}_{r,i}, 0)$ and absorption be $\bar{b}_{r,i} = \bar{d}_{r,i} + \bar{M}_{r,i}$. Then the top-Armington shares (Cal-10) and the CET shares (Cal-11) are:

$$\bar{s}^{d}_{r,i} = \frac{\bar{d}_{r,i}}{\bar{b}_{r,i}}, \quad \bar{s}^{m}_{r,i} = \frac{\bar{M}_{r,i}}{\bar{b}_{r,i}}; \tag{Cal-10}$$

$$\bar{s}^{cd}_{r,i} = \frac{\bar{d}_{r,i}}{\bar{X}_{r,i}}, \quad \bar{s}^{ce}_{r,i} = \frac{\bar{E}_{r,i}}{\bar{X}_{r,i}}. \tag{Cal-11}$$

The bilateral source shares $\bar{s}^{w}_{exp\to r,i} = \bar{XW}_{exp,r,i}/\bar{M}_{r,i}$ used in (T-5)–(T-6) are formed in the model builder from $\bar{XW}$ and $\bar{M}$. These shares populate the Armington demand (T-1)–(T-3), the bilateral sourcing (T-5)–(T-6) and the CET allocation (T-7)–(T-8).

4.5 Income, saving and the foreign balance

Household factor income folds the six raw factors into three and sums (Cal-12):

$$\bar{YF}_{r,\text{fmap}(f)} \mathrel{+}= M[\text{HH:}r,\ \text{FAC:}r\text{:}f], \qquad \bar{YH}_r = \sum_f M[\text{HH:}r,\ \text{FAC:}r\text{:}f]. \tag{Cal-12}$$

Household and government saving are read from the investment column (Cal-13):

$$\bar{Sh}_r = M[\text{INV:}r,\ \text{HH:}r], \qquad \bar{Sg}_r = M[\text{INV:}r,\ \text{GOV:}r] - M[\text{GOV:}r,\ \text{INV:}r]. \tag{Cal-13}$$

The savings rate and the direct-tax rate are ratios to income (Cal-14):

$$\overline{aps}_r = \frac{\bar{Sh}_r}{\bar{YH}_r}, \qquad \tau^{d}_{r} = \frac{M[\text{DTAX:}r,\ \text{HH:}r]}{\bar{YH}_r}. \tag{Cal-14}$$

The crucial *foreign-saving* balance (Cal-15) is the net capital inflow from *all* other regions plus the legacy single-account RoW flow:

$$\bar{Sf}_r = \sum_{o\neq r} \Big(M[\text{INV:}r,\ \text{INV:}o] - M[\text{INV:}o,\ \text{INV:}r]\Big) + \Big(M[\text{INV:}r,\ \text{ROW}] - M[\text{ROW},\ \text{INV:}r]\Big). \tag{Cal-15}$$

The sum-over-all-other-regions form of (Cal-15) is essential for the benchmark to be an exact fixed point: the Rest-of-World's current account equals the negative sum of the chosen bloc's foreign-saving balances, so the global capital account closes. Government revenue at the benchmark is $\bar{GREV}_r = \bar{GEXP}_r + \bar{Sg}_r$ (revenue equals expenditure plus public saving). These quantities feed the income identities (Y-10)–(Y-16): $\overline{aps}$ into the saving rule (Y-12), $\bar{Sf}$ into the financing identity (Y-16), and the factor incomes into the benchmark start values.

4.6 The benchmark as a fixed point

With all coefficients defined by (Cal-1)–(Cal-15) and benchmark prices set to 1, the calibrated data satisfy every model equation at the benchmark: zero-profit holds because $\bar{a}^{nd1} + \bar{a}^{va} + \tau^p + \tau^i = 1$ by (Cal-4); the Leontief and CES demands return the benchmark quantities because their shares were read from those very quantities; the commodity and factor markets clear because the SAM is balanced; and the income identities hold because the SAM rows equal the SAM columns. A no-shock PATH solve therefore reproduces the data — the homogeneity test passes — and any scenario is a controlled departure from this fixed point. Two calibration choices were decisive for obtaining an *exact* fixed point in practice: the all-regions foreign-saving sum (Cal-15), and the per-bundle intermediate price (P-5) written so that $PND1 = 1$ at the benchmark; without them the benchmark residual is small but nonzero and the model is harder to solve.

Chapter 5

Linking the model to poverty and income inequality

The model solves for an economy: prices, outputs, factor returns, trade and the government account. Poverty and inequality are statements about households, and no aggregate of the first kind implies a statement of the second. A policy that raises GDP by two per cent can lower poverty by ten points or raise it, depending on whose wage moved, which sector expanded and what happened to the price of food. This chapter sets out the bridge between the two — what leaves the CGE, what receives it, and what comes back as a distribution — so that the poverty results reported in Chapter 6 can be read for what they are.

The method is the top-down-with-behaviour (TDB) microsimulation of the Partnership for Economic Policy [284], itself built on the income-generation model of Bourguignon, Fournier and Gurgand [34] and the macro–micro linkage of Robilliard, Bourguignon and Robinson [251]. CDCGE uses a Julia implementation of that toolkit, `TDBmicrosim`, in place of the original Stata code.

5.1 Why the CGE cannot answer the question on its own

A CGE model carries a *representative* household per region — in this build, one — and that household is an aggregate, not an average. Its consumption bundle is the economy's bundle and its income is the economy's income; it has no dispersion, so it cannot become poor. Distributional analysis inside such a model is possible only by splitting the aggregate into representative household groups, and that device answers half the question: it reports how the gap *between* groups moves while assuming the distribution *within* each group is policy-neutral. The empirical literature has found repeatedly that within-group inequality carries as much or more of the variation in total inequality as the between-group component [139, 206], so the assumption is not innocuous. A microsimulation, by contrast, keeps every surveyed household distinct but has no general equilibrium: it cannot say what a fuel tax does to the wage of an unskilled worker in manufacturing. Each model supplies what the other lacks [50].

5.2 The linkage this model uses

Of the linkage families in use — representative household groups, fully integrated, top-down micro-accounting, top-down with behaviour, bottom-up and iterative [50] — CDCGE uses **top-down with behaviour**. The CGE is solved first; its results are then passed down to the survey as exogenous changes.

The simpler top-down variant, micro-accounting, applies the envelope theorem: each household's welfare change is its net consumption of each good times the relative price change, plus its hours times the wage change, plus the change in other income [41]. It is exact for small shocks and it holds behaviour fixed, which for the shocks in this report — productivity gains sustained to 2040, tax changes of several points, world-price movements of a quarter — would overstate the damage and understate the adjustment, because no worker is allowed to change occupation. The behavioural variant estimates occupational choice, wages and self-employment income econometrically from the survey, and lets individuals move.

The linkage is one-way. The micro results do not feed back into the CGE, so the household side inherits the macro solution but cannot alter it. The size of the error this introduces is the size of the aggregation error between the surveyed households and the model's single household [284].

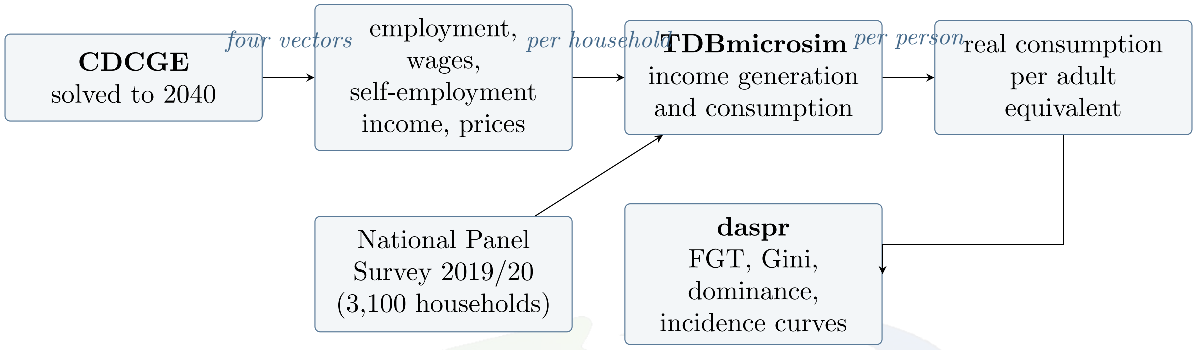

Figure 5.1: The linkage. The CGE is solved first and passes four vectors of changes down to the survey; the microsimulation rebuilds each household's income and deflates it by that household's own price index; the resulting welfare distribution is what the poverty and inequality battery is computed on. Nothing returns from the microsimulation to the CGE.

5.3 What crosses the boundary

Four vectors of changes, all measured against the model's own baseline rather than against observed history, pass from the CGE to the microsimulation [284]:

1. **Employment**, by skill and location — the number of workers, not the wage;
2. **Wage payroll**, by skill;
3. **Income from self-employment**, by skill, taken from the capital and land returns of the agricultural and non-agricultural activities;
4. **Commodity prices**, by consumption category.

Consistency is a requirement, not a hope. The two layers must carry the same labour-market segments and the same commodity categories, and after the microsimulation the change in *average* wages, in the number of workers by segment, in self-employment income per worker and in the consumer price vector must reproduce the CGE's changes. This is what makes the exercise a linkage rather than two models run side by side.

5.4 The income-generation model

Each working-age individual faces four mutually exclusive occupational states: wage worker, non-agricultural self-employed, farmer, and not working. The choice is estimated as a multinomial logit on age, education and household characteristics, with the household head estimated first and the other members conditional on that choice [34]. The residuals are drawn from the Gumbel distribution until the drawn set reproduces each individual's *observed* status, so the base year is recovered exactly and only the deterministic part of the model is recomputed under a scenario.

Movement between states is then imposed by a job-queuing rule [49]: if the CGE says skilled wage employment rises by three percentage points, working-age skilled individuals not already in wage work are ranked by their estimated probability of being there, and taken in descending order until the CGE's share is matched. Nobody moves between skill classes — an unskilled worker cannot become skilled within a simulation — while movement between occupations is free.

Wages follow a Mincer equation estimated by the Heckman two-step procedure, the selection equation correcting for the fact that wages are observed only for those in wage work [136]; individual residuals are retained for those observed in wage work and drawn from the relevant skill-specific variance for the rest. Household profit from farming and non-agricultural self-employment is estimated as a Cobb–Douglas function of household assets and the number of skilled and unskilled family workers, by instrumental variables because family labour is endogenous, and divided by the number of family workers to give a per-worker return. Total household income is then the sum of wage income over its wage workers, profit over its self-employed, and exogenous transfers — remittances and public transfers. The relative change in that total, not its level, is what is applied to the household's consumption [284].

5.5 Consumption, prices and the welfare variable

A price change does not fall equally on households that buy different things. To carry that heterogeneity, each household is given its *own* price deflator, its budget shares weighting the commodity price changes; welfare is then expressed as *equivalent income* in the sense of King [172] — the income that, at base-year prices, would leave the household as well off as its actual consumption at scenario prices. Under the Cobb–Douglas preferences the toolkit assumes, that deflator is the budget-share-weighted geometric mean of the price relatives.

The welfare variable that results — real consumption per adult equivalent, in base-year prices, for every person in the survey — is the single quantity on which everything in the distributional chapter is computed.

5.6 From welfare to poverty and inequality

Against a poverty line z, the Foster–Greer–Thorbecke family [124] summarises the distribution at three depths: the headcount ($\alpha = 0$), the average normalised gap ($\alpha = 1$) and its square ($\alpha = 2$), which weights the poorest most. Inequality is read from the single-parameter Gini class, the standard index being the case $\rho = 2$, and from the Atkinson and generalised-entropy families at several aversion parameters. Three further readings are taken because a single index at a single line can mislead:

- **Stochastic dominance**, which asks whether poverty falls at *every* line over a range rather than at the one chosen, and at second order whether the conclusion survives any distribution-sensitive index [284];
- **Decomposition by income source**, which attributes the change to wages, profits and consumer prices using the Shapley value [255, 26];
- **Growth incidence curves**, the growth in welfare at each percentile of the distribution, which show whether a gain was pro-poor in the relative sense [243].

The indices, their standard errors, the paired difference tests and the dominance curves are computed with the DASP routines of Araar and Duclos [23]; CDCGE calls `daspr`, an R port of that package. Because the occupational and income residuals are random draws, each scenario is replicated and the median taken for every estimator, with confidence intervals from the replicates [284].

5.7 What the linkage cannot do

Four limits travel with the method and are worth stating before the results rather than after them.

- **No feedback.** The micro results never reach the CGE, so a change in the distribution cannot alter labour supply, savings or demand in the macro solution.
- **Behaviour is fixed at the base year.** The logit, wage and profit parameters are estimated once on the survey and held constant to 2040. A structural break in how Ugandans choose occupations would not be captured.
- **The population ages statically.** Sampling weights are projected forward so that the simulated population matches the macro path [88]; household composition, schooling and migration are not re-simulated. This is the usual short-to-medium-run choice, and it is being asked here to carry a twenty-year horizon.
- **The survey is a sample.** Every index inherits its sampling error, which is why differences are reported with standard errors and why district-level readings in the spatial section are masked where the cell is thin.

5.8 How this is realised in CDCGE

The application in this report makes the following choices, each of which is visible in the results that follow:

- The micro-base is the **Uganda National Panel Survey 2019/20**, the most recent Ugandan survey in the household-survey store, carrying about 3,100 households and their members.
- **Skill** is defined by education: a worker is skilled on completing senior four.
- The CGE's nine sectors are mapped to the **thirty consumption categories** of the survey by an explicit concordance, so that the commodity price vector reaches household budgets. Those thirty categories cover about ninety per cent of recorded spending, and the welfare aggregate is grossed up accordingly.
- Sampling weights are projected to **2040**, the model's horizon, so that every scenario can be read at the same date as the macro results.
- The poverty line is Uganda's **official national line** — 32,106 shillings per adult equivalent per month at 2005/06 prices — with the welfare variable rescaled so that the line sits at 100. A second line at 139.1 on the same scale corresponds to the international \$3.00 a day at 2021 purchasing power parity, and every index is reported at both.

The baseline this produces puts the 2040 headcount at the national line at 18.4 per cent. Chapter 6 opens its distributional section with Uganda's measured record — where poverty and inequality actually stand and how they have moved — before turning to what the simulated packages do to them.

Chapter 6

Simulations

This chapter reports the simulation study in full: all 209 policy levers the application carries, each solved individually against one common baseline to 2040; the Ugandan context for every lever, drawn from the published record and set against the country's neighbours; a distributional analysis of twenty-two policy packages through the microsimulation and DASP; and the spatial incidence of each package by region and district. Nothing in it is typed by hand — every table and every figure is generated from the solved runs, and the sources for the country context are listed in the References.

6.1 Background on the simulations used

The simulations are produced with the **CDCGE** engine: a country-disaggregated, multi-sector, recursive-dynamic computable general equilibrium model calibrated to Uganda from the GTAP 11 data base, in which the country is an individual region[1]. Each period the static equilibrium is solved as a mixed complementarity problem with the PATH solver; factor endowments and autonomous demand then grow along a balanced-growth path, so that under no policy shock real output grows at a constant rate. That path is the *baseline*.

A *simulation* applies a policy lever as a shock to the relevant productivity, factor-supply, tax, trade-cost or world-price channel, over the intervention window, and reports the resulting path as a percentage *deviation from the baseline*. Because the effects are traced in general equilibrium they capture spillovers to other sectors, to trade and to welfare, not only the direct impact of the instrument.

6.1.1 What is reported

Every lever is solved *on its own* against one common baseline, which is solved once and reused. That matters more than it appears: a CGE path is the output of a sequence of complementarity solves, and a baseline re-solved for each scenario would carry its own solver trajectory, so differences between levers would partly be differences between baselines.

Two outcome columns are reported at each horizon. **GDP** is the base-weighted real index. **Welfare** is the model's own real-consumption welfare measure for Uganda, not a proxy: it moves with the cost of living as well as with income, which is why a lever that lowers food prices can raise welfare by more than it raises output.

6.1.2 Shock sizes, and why they are uniform

Levers of different kinds are not measured in the same units, so a table comparing them needs a convention:

[1] A. Aguiar et al., "The GTAP Data Base: Version 10", *Journal of Global Economic Analysis* 4(1), 2019. https://doi.org/10.21642/JGEA.040101AF

- **Sector productivity levers** run at **intensity 1.0**, each lever's own documented full effect delivered over the intervention window. The interface allows any intensity; 1.0 is the calibrated step, not a maximum.
- **Fiscal and external instruments** run at **ten of their own interface steps** above neutral — five percentage points on a commodity tax rate, ten per cent on a world price. One step was tried first and rejected: over a twenty-four-year path a single step is a rounding error, and every instrument would have been reported as inert.

These are units of measurement, not policy recommendations. A lever's position says how much the model thinks that instrument moves per unit of instrument; whether the unit is affordable or achievable is a separate question this report does not answer.

6.2 Sector productivity levers

This chapter reports the 74 sector productivity levers the application carries, each solved individually to 2040. Of the 74 instruments only **63** produce a distinct answer: the remainder are tied, because instruments naming medium-30 commodities are retargeted onto the nine sectors this build carries and several then become the same shock. The ties are shown rather than hidden, since a reader is entitled to know the model was not asked the question at a resolution that could separate them.

6.2.1 Crops

In this run the strongest lever in Crops is **Irrigation expansion** (+2.81% GDP, +3.65% welfare at 2040), while **Improved seed** delivers the smallest GDP effect (+0.70%). The median lever in the group moves GDP by +1.57%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Irrigation expansion	+1.59	+2.81	+2.00	+3.65
High-value crop diversification	+1.35	+2.42	+1.68	+3.12
Export-crop promotion	+1.27	+2.28	+1.57	+2.92
Mechanization	+0.93	+1.63	+1.14	+1.98
Feeder roads to farms	+0.86	+1.52	+0.98	+1.68
Fertilizer	+0.75	+1.35	+0.92	+1.66
Reduced post-harvest loss	+0.75	+1.35	+0.92	+1.66
Improved seed	+0.39	+0.70	+0.47	+0.81

Table 6.1: Crops: deviation from the balanced-growth baseline.

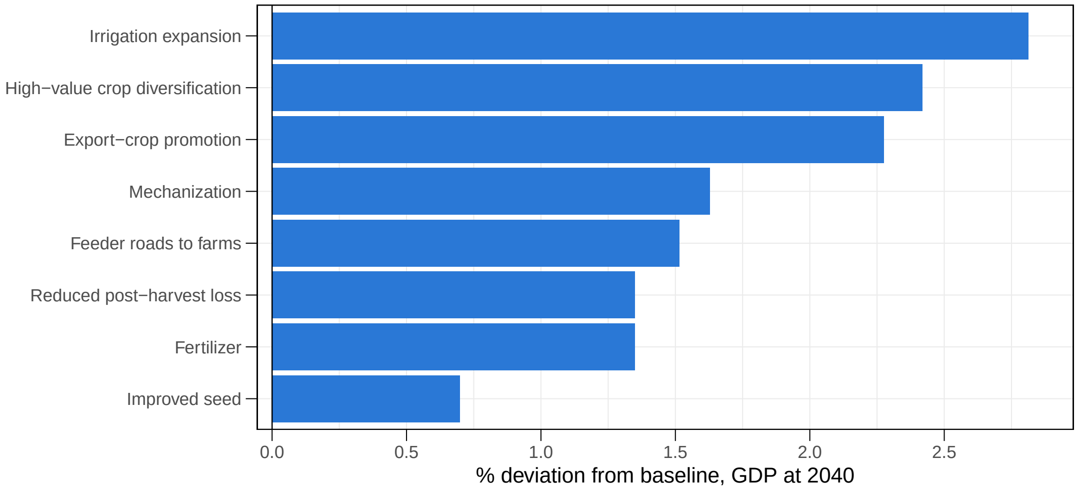

Figure 6.1: Crops: GDP deviation from baseline at 2040, by lever.

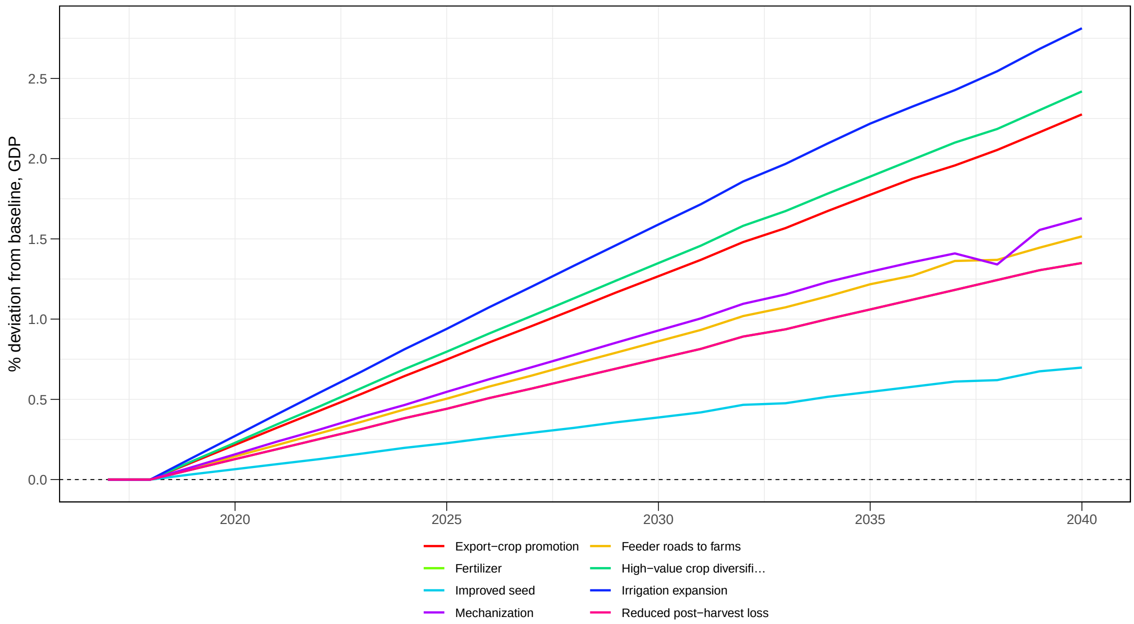

Figure 6.2: Crops: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Irrigation expansion. Uganda irrigates almost none of its farmland. The Ministry of Water and Environment puts the irrigable potential at about 3.0 million hectares and the equipped area at roughly 77,000 hectares, under 2 per cent of potential; coverage of cultivated land is about 0.5 per cent against 3.6 per cent in Tanzania and 2.0 per cent in Kenya [203]. The country had no irrigation policy from independence until the National Irrigation Policy of 2017, which sets a target of 1.5 million hectares irrigated by 2040 [132]. The World Bank's Irrigation

Modernisation Project and its micro-irrigation programme are the main public vehicles, and their own appraisal notes that rain-fed yields fall by a third or more in a dry season that now arrives more often [358].

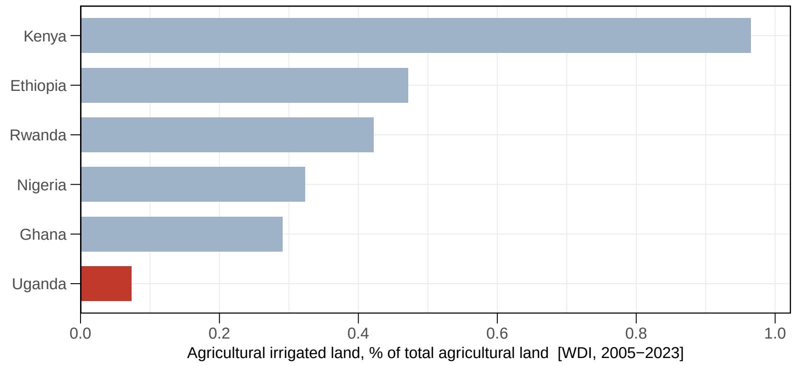

Figure 6.3: Uganda against its peers: Agricultural irrigated land (% of total agricultural land). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +1.59% in 2030 and +2.81% by 2040 against the balanced-growth baseline, and welfare by +2.00% and +3.65%. It ranks 1 of 8 in its group on GDP at 2040, the strongest lever in the group.

High-value crop diversification. Uganda is the second-largest producer of fresh fruit and vegetables in Sub-Saharan Africa after Nigeria, yet exported only about US$34 million of them in 2021; the sector's own target is US$1 billion [261, 48]. Floriculture is already the third-largest non-traditional export after gold and fish, and non-traditional exports as a group have overtaken coffee, cotton, tea and tobacco [207]. The binding constraints identified by Swisscontact's work on sanitary and phytosanitary compliance are certification, cold chain and air-freight cost rather than agronomy [261, 13]. This lever is the economy-wide counterpart: a shift of crop output toward the higher-value lines.

Result. In the model this lever moves GDP by +1.35% in 2030 and +2.42% by 2040 against the balanced-growth baseline, and welfare by +1.68% and +3.12%. It ranks 2 of 8 in its group on GDP at 2040.

Export-crop promotion. Coffee is the test case. Uganda became Africa's largest coffee exporter in 2025, shipping 7.7 million 60-kg bags (462,000 tonnes) worth US$2.2 billion in 2024/25, double the previous year, on a 25 per cent rise in volume and a 33–80 per cent rise in robusta and arabica prices [97, 51]. The USDA's coffee annual and the Uganda Coffee Development Authority attribute the volume to a decade of seedling distribution and to Coffee Roadmap targets of 20 million bags [343, 301]. The price component of that windfall is exogenous and is the subject of the world-price chapter; this lever isolates the domestic productivity side of export-crop promotion across coffee, tea, cotton and cocoa.

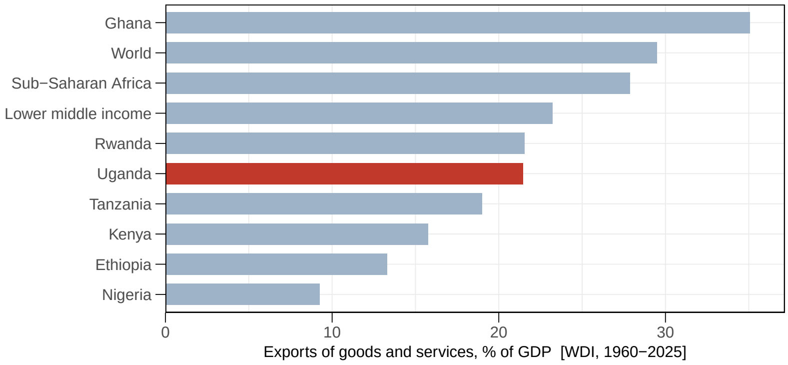

Figure 6.4: Uganda against its peers: Exports of goods and services (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +1.27% in 2030 and +2.28% by 2040 against the balanced-growth baseline, and welfare by +1.57% and +2.92%. It ranks 3 of 8 in its group on GDP at 2040.

Mechanization. Ugandan agriculture runs on the hand hoe. MAAIF's own survey finds over 90 per cent of farm operations done with hand tools and household labour, about 8 per cent with animal traction and under 2 per cent with tractors [188]. FAO puts farm power in developed agriculture at around 200 tractors per 100 square kilometres of arable land against a Sub-Saharan average of 27 [68]; Uganda does not report the WDI tractor series at all. Government's response has been direct distribution of tractors through district mechanisation centres and presidential initiatives [237], an approach the literature on African mechanisation generally finds less durable than hire markets.

Result. In the model this lever moves GDP by +0.93% in 2030 and +1.63% by 2040 against the balanced-growth baseline, and welfare by +1.14% and +1.98%. It ranks 4 of 8 in its group on GDP at 2040.

Feeder roads to farms. About 80 per cent of Uganda's rural road network is earth surface that becomes impassable in the rains, and an Economic Policy Research Centre survey finds only about a third of rural roads in good or fair condition [70, 106]. The World Bank's Rural Access Index puts the share of rural people within two kilometres of an all-season road at roughly 62 per cent in Uganda [371]. Community access roads fall to local governments that cannot fund them; the FY2022/23 budget set aside UGX 178.5 billion for district, urban and community access roads. District case studies link road condition directly to market participation and farm-gate prices [156].

Result. In the model this lever moves GDP by +0.86% in 2030 and +1.52% by 2040 against the balanced-growth baseline, and welfare by +0.98% and +1.68%. It ranks 5 of 8 in its group on GDP at 2040.

Fertilizer. Uganda applies less mineral fertilizer than almost any country in the world. The World Development Indicators record 3.3 kg of nutrient per hectare of arable land in 2023, against 50 in Kenya, 32 in Rwanda, 21 in Tanzania, a Sub-Saharan average of 20 and a world average of 138 [374]. The Economic Policy Research Centre attributes the gap to policy rather than agronomy: soils are among the most nutrient-depleted in Africa, yet input markets are thin, prices high and quality unreliable, with IFDC market tests finding a large share of bagged product under-weight or adulterated [101, 143]. Government's own review concludes that Uganda has had a "deliberately weak" fertilizer policy, and its 2016 National Fertilizer Policy targets 50 kg/ha by 2040 [98].

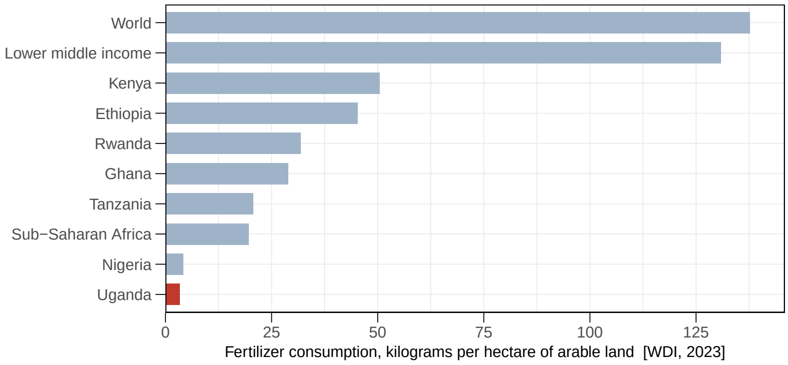

Figure 6.5: Uganda against its peers: Fertilizer consumption (kilograms per hectare of arable land). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.75% in 2030 and +1.35% by 2040 against the balanced-growth baseline, and welfare by +0.92% and +1.66%. It ranks 6 of 8 in its group on GDP at 2040.

Reduced post-harvest loss. FAO's food-loss analysis for Uganda estimates that 17.6 per cent of grain (maize, millet, rice) is lost after harvest, about 2.8 million tonnes a year, with maize alone losing 12.4 per cent; the critical loss points are drying, farmer storage and milling, and the damage includes aflatoxin contamination that closes export markets [112, 42]. A joint Government–FAO–WFP–IFAD strategy for grains followed [114]. Household-level work by the Economic Policy Research Centre and ordered-probit studies of maize and sweet potato chains find that hermetic storage and drying practice explain most of the variation between farmers [102, 121]. Losses of this size mean a productivity gain from storage costs no land and no input.

Result. In the model this lever moves GDP by +0.75% in 2030 and +1.35% by 2040 against the balanced-growth baseline, and welfare by +0.92% and +1.66%. It ranks 7 of 8 in its group on GDP at 2040.

Improved seed. Fewer than a fifth of Ugandan farmers plant certified improved seed, against 50–75 per cent in Kenya or South Africa [152]. Bagamba and colleagues trace the shortfall to both sides of the market: a formal seed system that covers a handful of crops, a Quality Declared Seed class introduced to reach the rest, and a widespread and partly justified belief that what is sold as improved seed is not [85, 14]. Feed the Future's monitoring of agro-dealers finds counterfeiting a live concern along the chain [342], while randomised trials show adoption responds to information and trust as much as to price [118]. Cereal yields, the WDI proxy, stand at about 2.0 t/ha against 4.2 in world terms.

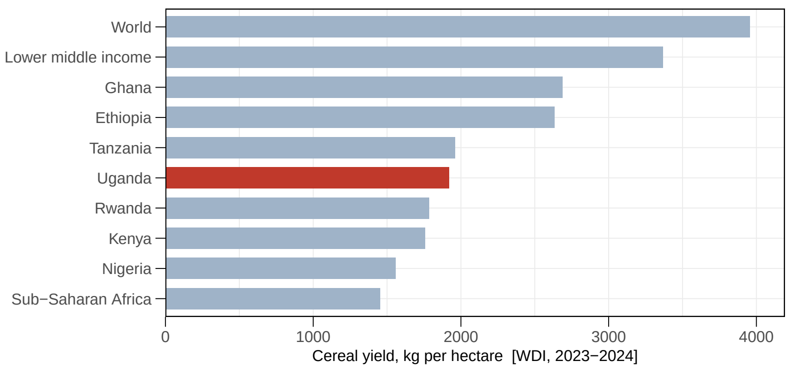

Figure 6.6: Uganda against its peers: Cereal yield (kg per hectare). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.39% in 2030 and +0.70% by 2040 against the balanced-growth baseline, and welfare by +0.47% and +0.81%. It ranks 8 of 8 in its group on GDP at 2040, the weakest.

6.2.2 Livestock

In this run the strongest lever in Livestock is **Dairy and meat processing** (+8.27% GDP, +8.17% welfare at 2040), while **Disease control** delivers the smallest GDP effect (+0.66%). The median lever in the group moves GDP by +0.89%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Dairy and meat processing	+4.55	+8.27	+4.41	+8.17
Cold-chain investment	+4.23	+7.69	+4.09	+7.59
Improved breeds	+0.55	+0.96	+0.55	+0.95
Veterinary services	+0.46	+0.83	+0.45	+0.84
Feed productivity	+0.42	+0.74	+0.42	+0.72
Disease control	+0.38	+0.66	+0.37	+0.63

Table 6.2: Livestock: deviation from the balanced-growth baseline.

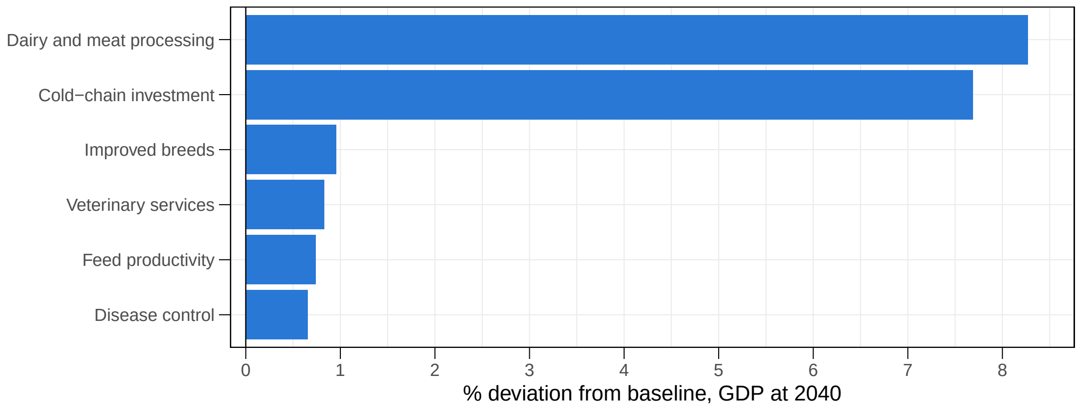

Figure 6.7: Livestock: GDP deviation from baseline at 2040, by lever.

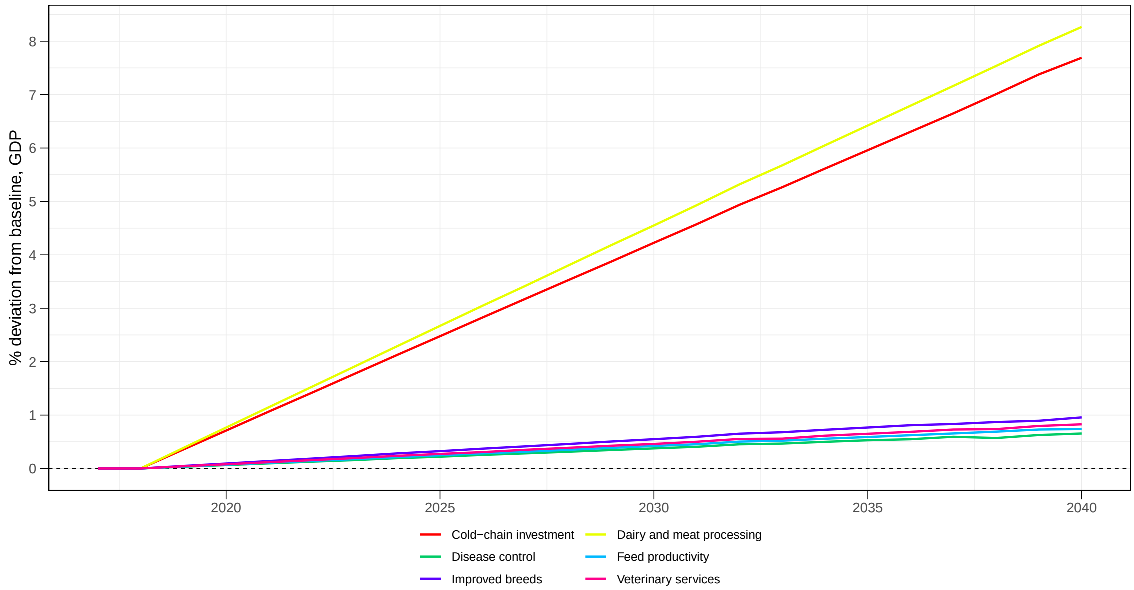

Figure 6.8: Livestock: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Dairy and meat processing. National milk output reached 5.4 billion litres in 2024, up from 2.5 billion in 2017/18, and dairy exports rose from US$92 million in FY2020/21 to US$280 million in FY2024/25 [44]. Uganda has 145 dairy plants with 3.4 million litres a day of capacity, used at about 69 per cent [44, 115]. Meat is the laggard: the domestic market is short by an estimated 900,000 tonnes a year, formal abattoir capacity is small, and exports go mainly to South Sudan, DRC and the EAC rather than to premium markets closed by disease status [304, 53]. Processing capacity here is a demand-side lever for the herd upstream.

Result. In the model this lever moves GDP by +4.55% in 2030 and +8.27% by 2040 against the balanced-growth baseline, and welfare by +4.41% and +8.17%. It ranks 1 of 6 in its group on GDP at 2040, the strongest lever in the group.

Cold-chain investment. Post-harvest milk losses in Uganda are estimated at 20–40 per cent, about US$23 million a year, concentrated in the rainy-season glut and in the evening milking that cannot reach a cooler before it spoils [356, 260]. Cooling capacity has grown from about 60 centres and 550,000 litres a day to 2.8 million litres, but 90 per cent of it sits in the Western and Central regions, and the centres depend on grid or diesel power that fails [226, 126]. Solar chillers and low-cost thermisation are the documented smallholder-scale responses [58, 260].

Result. In the model this lever moves GDP by +4.23% in 2030 and +7.69% by 2040 against the balanced-growth baseline, and welfare by +4.09% and +7.59%. It ranks 2 of 6 in its group on GDP at 2040.

Improved breeds. Indigenous cows in Uganda give about 3.5 litres a day; crossbreds average 13.6 litres, and adopting households raise milk output by more than 200 per cent [231]. Only 21 per cent of dairy households own an improved animal, from 38 per cent in the Western region to 2 per cent in the North [231]. Genomic work on central-Uganda crossbreds shows the trade-off: exotic blood raises yield but also disease susceptibility and mortality under local conditions [234], and community bull schemes under the Regional Pastoral Livelihoods project are the main channel for reaching pastoral herds [229].

Result. In the model this lever moves GDP by +0.55% in 2030 and +0.96% by 2040 against the balanced-growth baseline, and welfare by +0.55% and +0.95%. It ranks 3 of 6 in its group on GDP at 2040.

Veterinary services. FAO's access-to-livestock-services profile counts 372 registered veterinarians and 998 paraprofessionals in Uganda, which it scores as 8 and 5 per cent coverage of need [116]. Transaction-cost studies in Uganda and Kenya find that private delivery works only where herd density and purchasing power make a round trip pay, so paraprofessionals carry most rural animal health care [250, 128]. Where trained paraprofessionals operate, 83 per cent of farmers report improved farm performance and vaccination uptake rises [127]. A 2026 petition by 1,200 professionals against a steep rise in licensing fees illustrates how thin the regulated tier is [21].

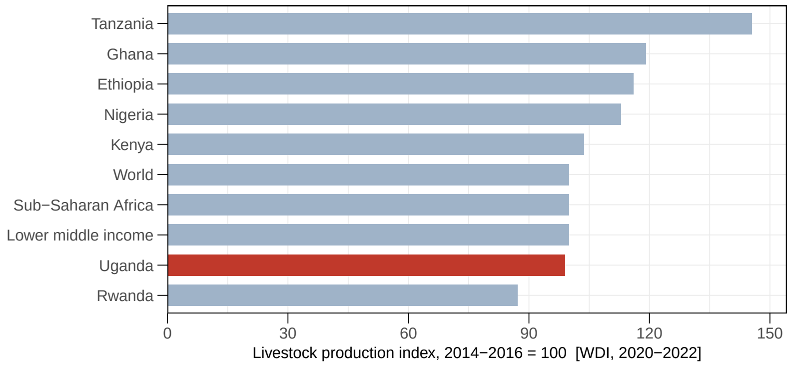

Figure 6.9: Uganda against its peers: Livestock production index (2014-2016 = 100). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.46% in 2030 and +0.83% by 2040 against the balanced-growth baseline, and welfare by +0.45% and +0.84%. It ranks 4 of 6 in its group on GDP at 2040.

Feed productivity. Feed is 70 per cent of production cost in Uganda's intensive poultry, pig and dairy systems, and FAO's ASL2050 spotlight names nutrition as the binding constraint in each [111, 113]. Extensive systems fare no better: natural pasture is the main feed source and is overgrazed to the point of species change and erosion [47]. The National Animal Feeds Policy and the 2023 Animal Feeds Bill respond to a compounding industry marked by poor formulation and counterfeit product [133, 63]. On-farm pasture trials show improved forages can double dry-matter yield on the same land.

Result. In the model this lever moves GDP by +0.42% in 2030 and +0.74% by 2040 against the balanced-growth baseline, and welfare by +0.42% and +0.72%. It ranks 5 of 6 in its group on GDP at 2040.

Disease control. Foot-and-mouth disease is endemic and recurs despite quarantine and vaccination; a systematic review of 2010–2021 records finds outbreaks in every year and every region [346, 245]. Quarantines close markets within 20 km for up to six months, and the losses along the marketing chain fall hardest on smallholders [347, 178]. FMD status is also what keeps Ugandan beef out of most export markets. Studies at the Uganda–Tanzania border show that control fails at shared watering points and through quarantine violations, which argues for regional rather than district-level control [232].

Result. In the model this lever moves GDP by +0.38% in 2030 and +0.66% by 2040 against the balanced-growth baseline, and welfare by +0.37% and +0.63%. It ranks 6 of 6 in its group on GDP at 2040, the weakest.

6.2.3 Forestry and fisheries

In this run the strongest lever in Forestry and fisheries is **Aquaculture expansion** (+13.35% GDP, +13.67% welfare at 2040), while **Capture-fisheries management** delivers the smallest GDP effect (+3.96%). The median lever in the group moves GDP by +8.88%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Aquaculture expansion	+7.37	+13.35	+7.26	+13.67
Plantation forestry	+5.52	+10.03	+5.38	+10.04
Wood and panel processing	+4.88	+8.88	+4.74	+8.85
Sustainable harvest management	+2.53	+4.59	+2.43	+4.43
Capture-fisheries management	+2.18	+3.96	+2.09	+3.80

Table 6.3: Forestry and fisheries: deviation from the balanced-growth baseline.

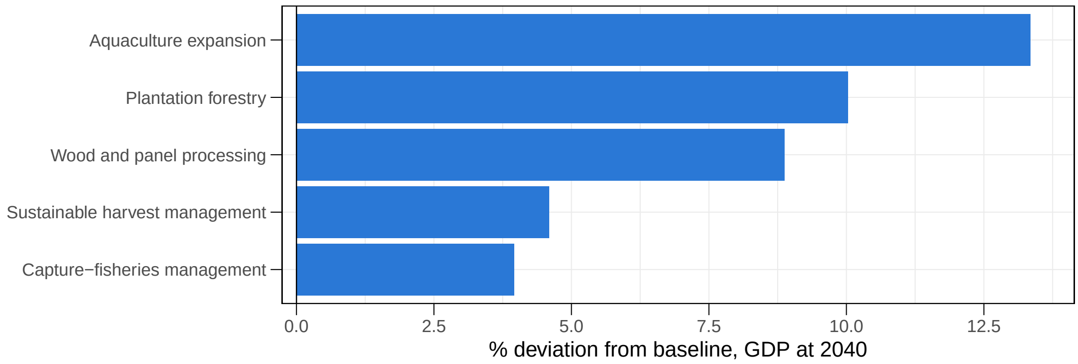

Figure 6.10: Forestry and fisheries: GDP deviation from baseline at 2040, by lever.

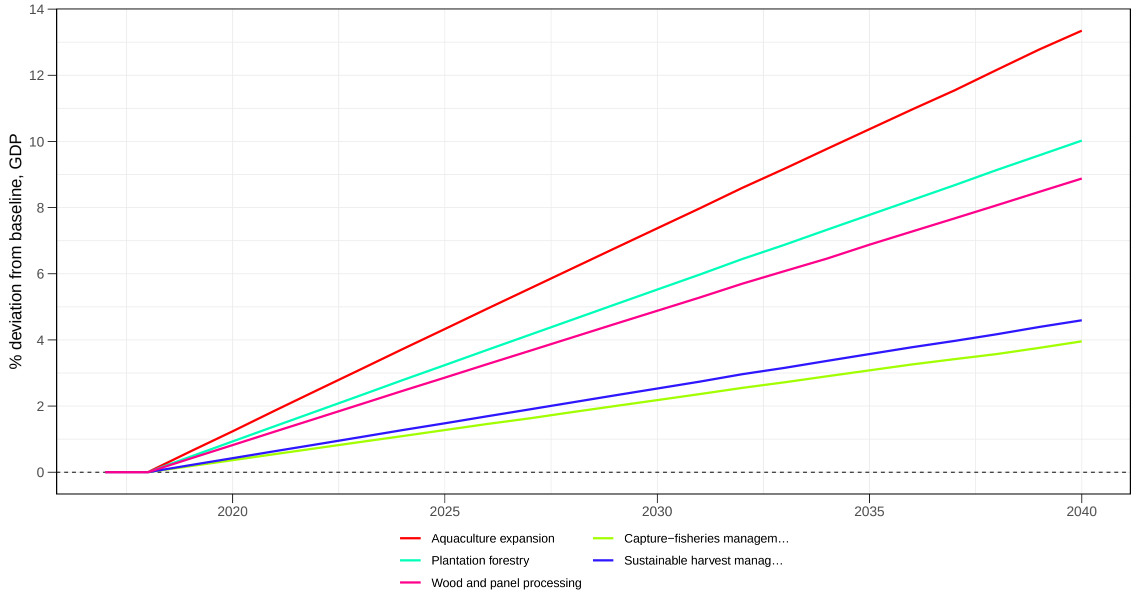

Figure 6.11: Forestry and fisheries: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Aquaculture expansion. Aquaculture is the fastest-growing food sector in Uganda. Output rose from under 1,000 tonnes in 2006 to well over 100,000 tonnes by 2019–2021, almost all Nile tilapia in cages on Lake Victoria, with yields of up to 60 kg per cubic metre under good management [147, 164]. The Netherlands' aquaculture road map identifies feed cost and fingerling quality as the constraints [214], and LVFO guidelines exist for siting cages [177]. The environmental literature is cautious: cage effluent and escapees raise water-quality concerns that a sector growing this fast has not yet resolved [131, 267].

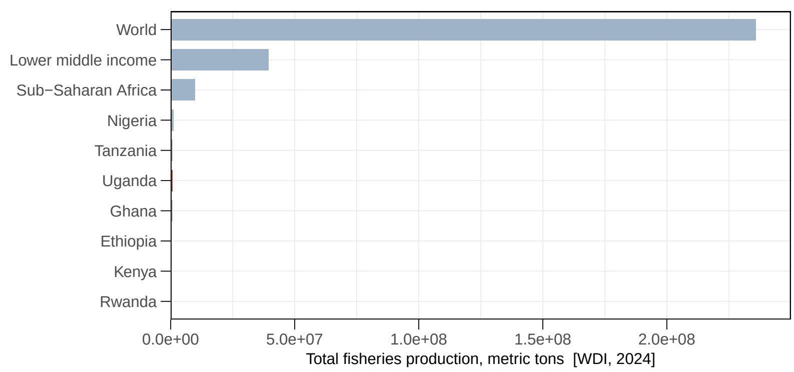

Figure 6.12: Uganda against its peers: Total fisheries production (metric tons). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +7.37% in 2030 and +13.35% by 2040 against the balanced-growth baseline, and welfare by +7.26% and +13.67%. It ranks 1 of 5 in its group on GDP at 2040, the strongest lever in the group.

Plantation forestry. The Sawlog Production Grant Scheme, financed by the EU and run with FAO since 2004, is the one African plantation programme the forestry literature calls a success: it paid private growers a grant per hectare against verified planting standards and established some 80,000 hectares of quality plantation in its first phases, with over 200,000 hectares of commercial forest now planted in the country [151, 117]. Out-grower schemes such as Namwasa show how smallholders join [291]. The World Bank's value-chain review finds the constraint has shifted downstream: a plantation estate now maturing faster than the sawmilling and market capacity to absorb it [360].

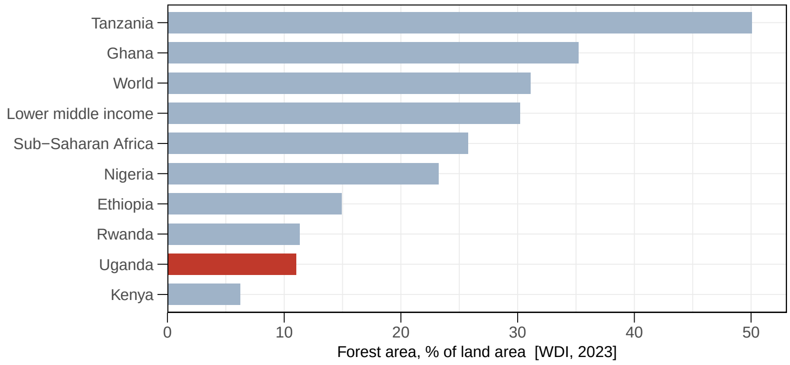

Figure 6.13: Uganda against its peers: Forest area (% of land area). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +5.52% in 2030 and +10.03% by 2040 against the balanced-growth baseline, and welfare by +5.38% and +10.04%. It ranks 2 of 5 in its group on GDP at 2040.

Wood and panel processing. The World Bank's review of the commercial forestry chain finds a processing sector of mobile and semi-mobile sawmills, high wastage and little seasoning, with Ugandan timber trading about 25 per cent below Kenyan prices — a discount that erodes the incentive to replant [360]. Small furniture workshops are 26 per cent of all manufacturing establishments, almost all informal [248, 249]. FAO's wood-processing and value-addition project, launched in 2023, is the direct policy counterpart of this lever: it targets recovery rates, kiln drying and panel products so that the maturing plantation estate is not sold as poles and charcoal [117].

Result. In the model this lever moves GDP by +4.88% in 2030 and +8.88% by 2040 against the balanced-growth baseline, and welfare by +4.74% and +8.85%. It ranks 3 of 5 in its group on GDP at 2040.

Sustainable harvest management. Uganda's forest cover fell from about 35 per cent a century ago to roughly 12 per cent, one of the fastest rates of loss recorded anywhere; recent estimates put annual loss at 38,000–88,000 hectares [86, 330]. Global Forest Watch attributes 94 per cent of loss to shifting agriculture, and charcoal — illegal but the main cooking fuel outside towns — drives degradation of what remains [123, 145]. The REDD+ readiness programme and the Bonn Challenge pledge commit Uganda to 21 per cent cover by 2030 [122]. This lever models the productivity of managed rather than mined forest.

The benchmark for this lever is Figure 6.13.

Result. In the model this lever moves GDP by +2.53% in 2030 and +4.59% by 2040 against the balanced-growth baseline, and welfare by +2.43% and +4.43%. It ranks 4 of 5 in its group on GDP at 2040.

Capture-fisheries management. The capture fishery is in decline. Landings from all water bodies were 280,600 tonnes in 2020, about half the level of fifteen years earlier, and Nile perch factories fell from 26 in 2012 to fewer than six [74, 314]. Stock assessments for Lake Victoria set rebuilding targets for the three main stocks [29]. Military enforcement since 2017 halved the use of monofilament nets yet stocks kept falling, which the Pulitzer Center's reporting attributes to unenforced mesh rules in the silverfish fishery and to the swim-bladder trade [239, 59, 176]. Exports were 23,141 tonnes worth US$146 million in 2019/20. The lever models the productivity gain from a managed, rebuilt stock.

The benchmark for this lever is Figure 6.12.

Result. In the model this lever moves GDP by +2.18% in 2030 and +3.96% by 2040 against the balanced-growth baseline, and welfare by +2.09% and +3.80%. It ranks 5 of 5 in its group on GDP at 2040, the weakest.

6.2.4 Mining and extraction

In this run the strongest lever in Mining and extraction is **New mine investment** (+14.92% GDP, +15.44% welfare at 2040), while **Energy-cost reduction for mines** delivers the smallest GDP effect (+0.17%). The median lever in the group moves GDP by +2.84%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
New mine investment	+8.26	+14.92	+8.16	+15.44
Mineral beneficiation	+6.15	+11.21	+6.02	+11.40
Local-content procurement	+2.88	+5.34	+2.77	+5.35
Export corridor for minerals	+0.15	+0.34	+0.49	+1.08
Royalty and tax regime	+0.09	+0.18	+0.30	+0.57
Energy-cost reduction for mines	+0.10	+0.17	+0.07	+0.12

Table 6.4: Mining and extraction: deviation from the balanced-growth baseline.

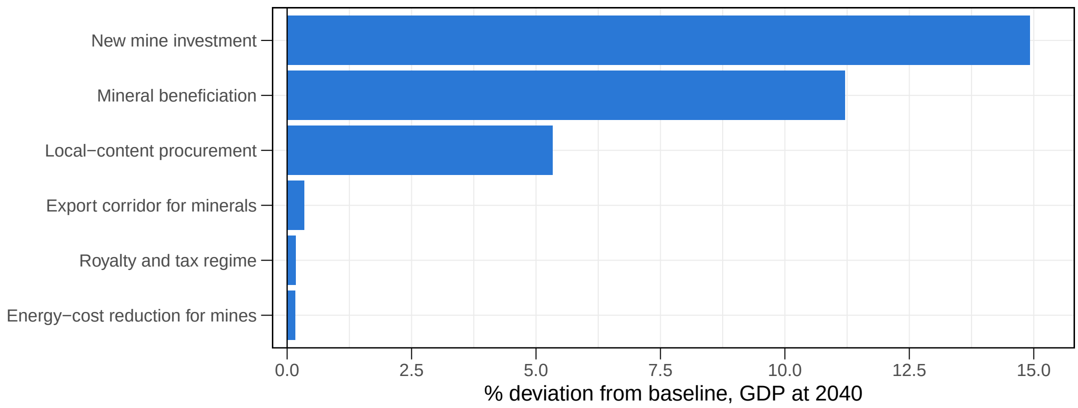

Figure 6.14: Mining and extraction: GDP deviation from baseline at 2040, by lever.

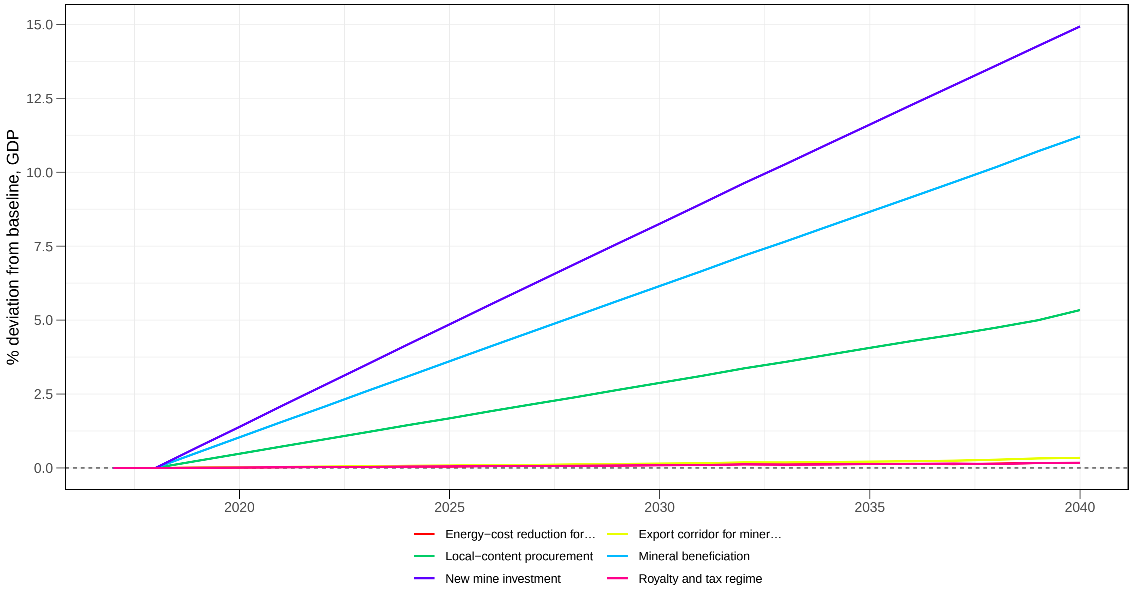

Figure 6.15: Mining and extraction: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

New mine investment. Mining and quarrying is 1.3 per cent of Uganda's GDP, yet gold was 40 per cent of merchandise exports in 2024 (US$4.2 billion of US$10.6 billion) — most of it re-exported metal refined from imported and artisanal supply rather than mined at scale [293, 309]. The first large-scale mine, Wagagai in Busia, opened in 2025 on a US$250 million Chinese investment to process 5,000 tonnes of ore a day for about 1.2 tonnes of gold a year [187, 130]. The Mining and Minerals Act 2022 formalised licensing and created a state mining company [31]. Mineral rents are under 1 per cent of GDP against 3–5 per cent in Tanzania and Ghana.

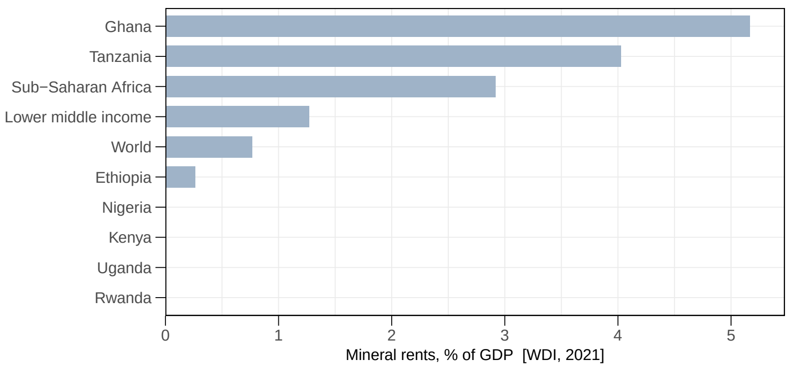

Figure 6.16: Uganda against its peers: Mineral rents (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +8.26% in 2030 and +14.92% by 2040 against the balanced-growth baseline, and welfare by +8.16% and +15.44%. It ranks 1 of 6 in its group on GDP at 2040, the strongest lever in the group.

Mineral beneficiation. Uganda banned the export of unprocessed minerals in stages, extending the moratorium to all raw materials including gold, lithium and tin in 2026 [282, 9]. The case for it is the price step between raw and processed product — vermiculite at about US$25 a tonne raw against US$410 processed [306] — and the country now has nine gold refineries and, since 2024, a tin smelter at Mbarara [293]. The case against, made by the Chamber of Mines, is that where domestic processing capacity does not yet exist the ban closes mines rather than opening smelters [289, 316]. This lever models the productivity of beneficiation itself, not the ban.

Result. In the model this lever moves GDP by +6.15% in 2030 and +11.21% by 2040 against the balanced-growth baseline, and welfare by +6.02% and +11.40%. It ranks 2 of 6 in its group on GDP at 2040.

Local-content procurement. Uganda's national-content regime for oil and gas, built on the 2008 National Oil and Gas Policy and the Petroleum Authority's guidelines, requires operators to weight Ugandan goods, services and labour in every procurement and to file a national content plan with each bid [230, 61]. On the US$10 billion Tilenga, Kingfisher and EACOP projects, about US$2 billion of contracts have gone to Ugandan firms and some US$1.2 billion is budgeted for local contractors in construction [227, 285]. ACODE's review finds the binding limit to be supplier capability rather than the rules [3]. The lever applies the same logic to mining supply chains.

Result. In the model this lever moves GDP by +2.88% in 2030 and +5.34% by 2040 against the balanced-growth baseline, and welfare by +2.77% and +5.35%. It ranks 3 of 6 in its group on GDP at 2040.

Export corridor for minerals. Uganda's minerals leave by road through Kenya. Government now plans to link its new standard-gauge line to the Tanzanian network so that gold, copper and iron ore from the south-west can reach Dar es Salaam, with the line ending at Mpondwe on the DRC border [268, 280]. The Muko iron-ore deposits in Kabale and Kisoro are the test case: high-grade ore whose transport cost to a smelter has so far exceeded its value [175]. EACOP itself is a corridor for one commodity and its access roads are already being handed over [20]. The lever models the trade-cost reduction of a dedicated mineral route.

Result. In the model this lever moves GDP by +0.15% in 2030 and +0.34% by 2040 against the balanced-growth baseline, and welfare by +0.49% and +1.08%. It ranks 4 of 6 in its group on GDP at 2040.

Royalty and tax regime. The Natural Resource Governance Institute's 2018 review found Uganda's mining fiscal regime uncompetitive on paper and uncollected in practice [213]. The Mining and Minerals Act 2022 reset it: royalties shared 65 per cent to central government, 20 to districts, 10 to sub-counties and 5 to landowners; a free-carried state interest of up to 15 per cent in large and medium mines, the standard now in Tanzania, DRC and Ghana; and a national mining company [2, 205]. Tanzania charges 3 per cent on most minerals and 5 on diamonds and gemstones [262]. Ministry of Finance principles for mining taxation were published in 2025 [197].

Result. In the model this lever moves GDP by +0.09% in 2030 and +0.18% by 2040 against the balanced-growth baseline, and welfare by +0.30% and +0.57%. It ranks 5 of 6 in its group on GDP at 2040.

Energy-cost reduction for mines. Uganda's extra-large industrial tariff is about US¢5–5.5 per kWh, among the lowest in the region, against roughly US¢8 in Tanzania and 18–23 in Kenya;

Ethiopia is the only cheaper neighbour [269, 281]. The paradox the EastAfrican describes is that the same system charges households among the highest tariffs in East Africa to subsidise industry [269]. For mines the tariff is not the constraint; grid reach and reliability at remote sites are, and the extension of transmission to Karamoja and the south-west is what this lever stands for. Electricity use per head remains about 100 kWh, a tenth of the Sub-Saharan average.

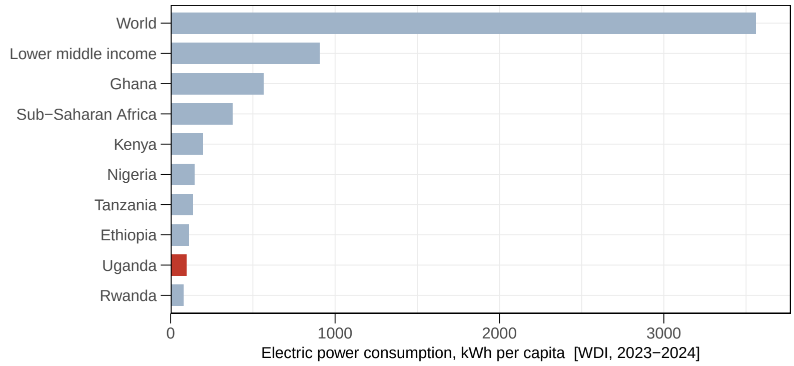

Figure 6.17: Uganda against its peers: Electric power consumption (kWh per capita). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.10% in 2030 and +0.17% by 2040 against the balanced-growth baseline, and welfare by +0.07% and +0.12%. It ranks 6 of 6 in its group on GDP at 2040, the weakest.

6.2.5 Manufacturing

In this run the strongest lever in Manufacturing is **Agro-processing expansion** (+10.03% GDP, +10.04% welfare at 2040), while **Lower power costs** delivers the smallest GDP effect (+0.20%). The median lever in the group moves GDP by +4.59%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Agro-processing expansion	+5.52	+10.03	+5.38	+10.04
Textiles and apparel upgrading	+5.20	+9.55	+5.06	+9.70
Industrial parks	+3.22	+5.87	+3.10	+5.76
Firm productivity upgrading	+2.53	+4.59	+2.43	+4.43
Import-tariff reform on inputs	+0.19	+0.40	+0.62	+1.28
Export incentives	+0.11	+0.21	+0.36	+0.69
Lower power costs	+0.12	+0.20	+0.09	+0.15

Table 6.5: Manufacturing: deviation from the balanced-growth baseline.

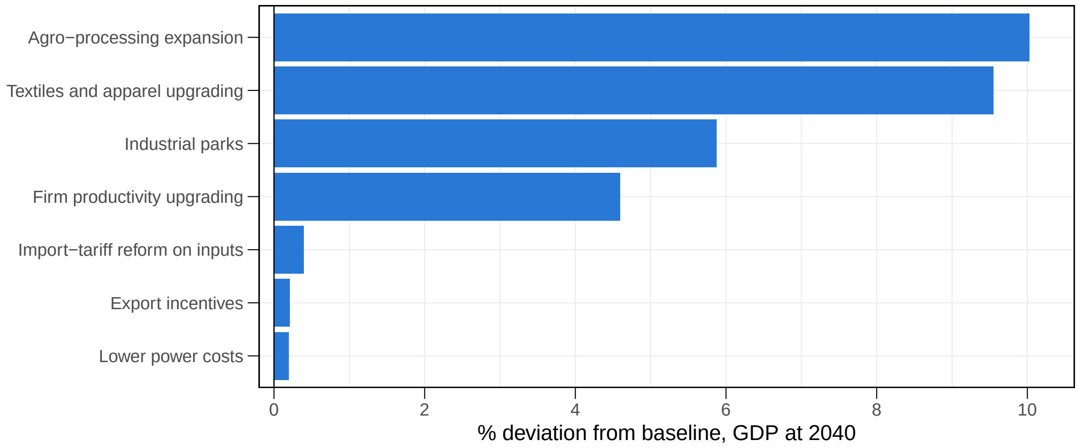

Figure 6.18: Manufacturing: GDP deviation from baseline at 2040, by lever.

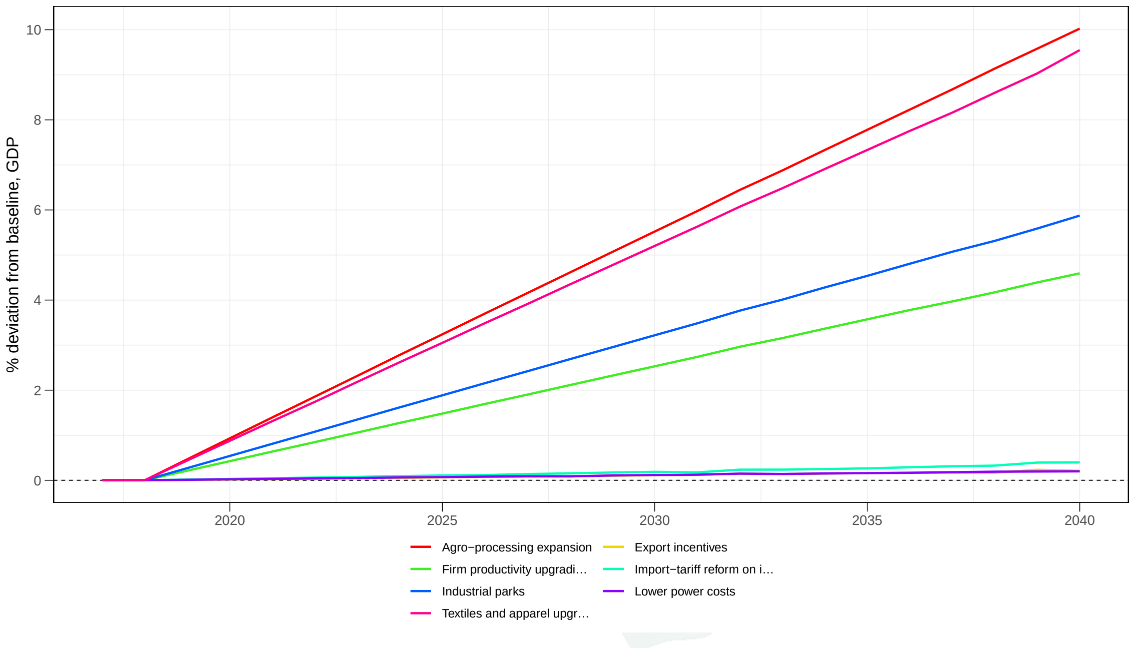

Figure 6.19: Manufacturing: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Agro-processing expansion. Manufacturing is about 9–10 per cent of Uganda's GDP (the WDI value-added series says 16 per cent on a broader definition) and agro-processing — milling, dairy, sugar, beverages, feed, fruit — is its largest component [321, 141]. Agriculture still supplies over half of export earnings, mostly as coffee, tea and fish with little transformation [141]. The Uganda Development Corporation's agro-manufacturing portfolio and the 2021 ban on unprocessed agricultural exports are the policy expression of this lever [303]. The AfDB's Eastern Africa manufacturing review finds the sector's productivity gap lies in scale and technology rather than raw-material supply [6].

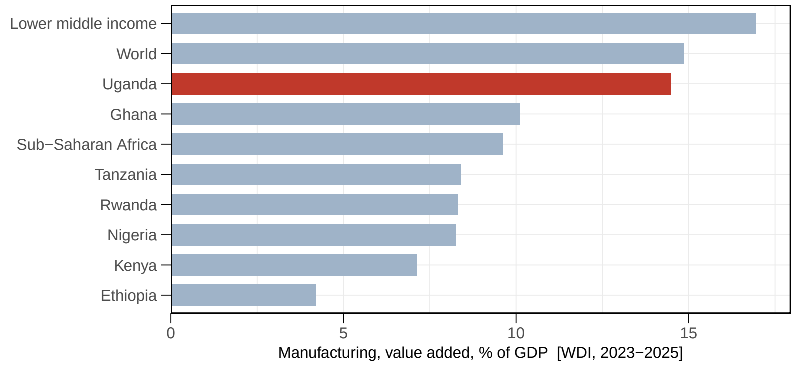

Figure 6.20: Uganda against its peers: Manufacturing, value added (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +5.52% in 2030 and +10.03% by 2040 against the balanced-growth baseline, and welfare by +5.38% and +10.04%. It ranks 1 of 7 in its group on GDP at 2040, the strongest lever in the group.

Textiles and apparel upgrading. Uganda grows some of the best cotton in Sub-Saharan Africa and exports over 90 per cent of it as lint; output fell from 470,000 bales in 1969 to about 209,000 in 2017/18 [263, 341]. Two integrated mills, Nytil at Jinja and Fine Spinners, consume a tenth of the lint and turn over about US$50 million, nearly double the value of raw-cotton exports [224, 270]. Uganda has earned little from AGOA against Kenya's and Ethiopia's US$200–400 million a year [11]. The 2023 ban on second-hand clothing imports, which are over 80 per cent of garment purchases, is the demand-side gamble [62, 168].

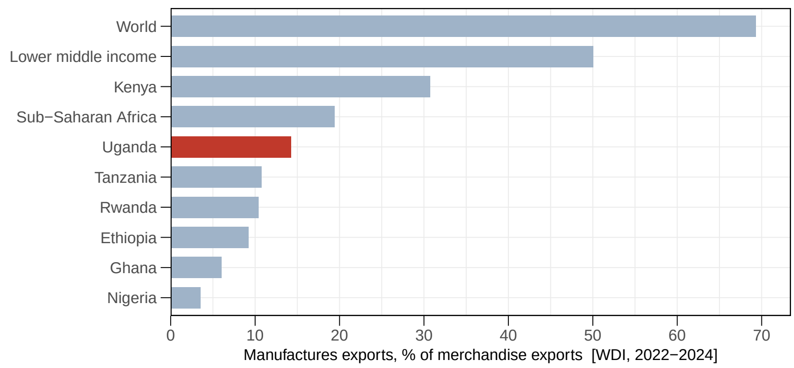

Figure 6.21: Uganda against its peers: Manufactures exports (% of merchandise exports). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +5.20% in 2030 and +9.55% by 2040 against the balanced-growth baseline, and welfare by +5.06% and +9.70%. It ranks 2 of 7 in its group on GDP at 2040.

Industrial parks. The Uganda Investment Authority runs eight public industrial and business parks and has supported three private ones; the eleven operating parks report about 42,500 direct and 60,000 indirect jobs, with the total across all parks now put at over 122,000 [307, 36]. Namanve hosts close to 300 factories and is planned for 500; Kapeeka, the Chinese-built Liao Shen park, runs 34 of 80 planned plants [305, 277]. Government's target is 25 parks by 2026 [307]. The international evidence on zones is mixed — they work where power, water and a road are the binding constraints and fail where the constraint is demand — and Uganda's parks are largely a bet on the first.

Result. In the model this lever moves GDP by +3.22% in 2030 and +5.87% by 2040 against the balanced-growth baseline, and welfare by +3.10% and +5.76%. It ranks 3 of 7 in its group on GDP at 2040.

Firm productivity upgrading. Productivity dispersion among Ugandan manufacturers is wide. The International Growth Centre's representative survey of small, medium and large firms finds the most productive firms several times more productive than the median in the same industry, with management practice and worker skill the main correlates [153]. Enterprise-survey work across developing countries shows informal firms at about a quarter of formal labour productivity, and formal firms competing with them at three-quarters of those that do not [367, 366]. The World Bank's 2025 enterprise survey for Uganda updates the picture [369]. The lever is an across-the-board TFP gain in manufacturing of the kind management-training and technology-extension programmes produce.

Result. In the model this lever moves GDP by +2.53% in 2030 and +4.59% by 2040 against the balanced-growth baseline, and welfare by +2.43% and +4.43%. It ranks 4 of 7 in its group on GDP at 2040.

Import-tariff reform on inputs. Uganda's tariff is the EAC Common External Tariff: 0 per cent on raw materials and capital goods, 10 on intermediates, 25 on finished goods, and since 2022 a fourth band of 35 per cent on goods the region says it can make [95, 99]. The problem for manufacturers is classification — many inputs land in the 10 or 25 per cent bands — which the duty-remission scheme and manufacturing-under-bond relieve only for exporters [320, 173]. The Economic Policy Research Centre's assessment of the 2022 CET is that its protective band raises input costs for the firms it means to help [99]. This lever models a cut in the effective tariff on manufacturing inputs.

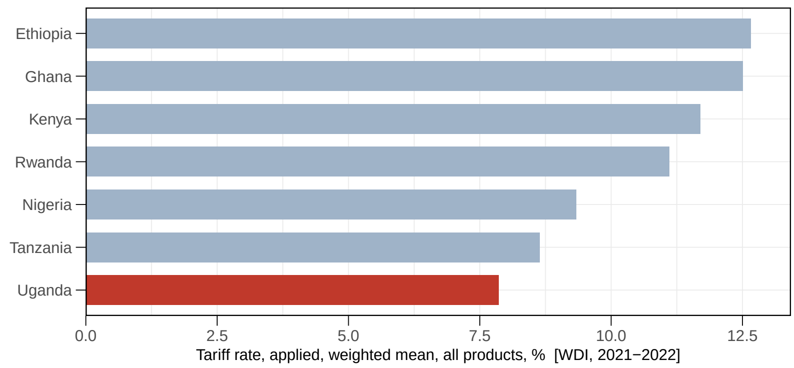

Figure 6.22: Uganda against its peers: Tariff rate, applied, weighted mean, all products (%). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.19% in 2030 and +0.40% by 2040 against the balanced-growth baseline, and welfare by +0.62% and +1.28%. It ranks 5 of 7 in its group on GDP at 2040.

Export incentives. Uganda's export incentives are the fixed duty-drawback scheme, manufacturing under bond, VAT zero-rating of exports and import-duty concessions on plant, all in place since the WTO's 2001 trade policy review [383, 322]. The Uganda Export Promotion Board, merged in 2024 with the Free Zones Authority into a single export and free-zones authority, licenses exporters and runs market-access programmes [202]. Manufactured goods are about a fifth of merchandise exports against a lower-middle-income average near 60 per cent. The lever represents a reduction in the cost of exporting manufactures equivalent to a broad export subsidy.

The benchmark for this lever is Figure 6.21.

Result. In the model this lever moves GDP by +0.11% in 2030 and +0.21% by 2040 against the balanced-growth baseline, and welfare by +0.36% and +0.69%. It ranks 6 of 7 in its group on GDP at 2040.

Lower power costs. World Bank enterprise surveys have found electricity the single largest drag on firm performance in Uganda since 2006, and the Bank's firm-level work on power constraints and total factor productivity puts a number on it: outages and self-generation cost manufacturers several points of TFP [370, 368]. The published tariff is not the problem — extra-large industry pays about US¢5.5 per kWh, cheaper than Tanzania and a quarter of Kenya [269] — so the lever is best read as the cost of *reliable* power: fewer interruptions, less diesel back-up, and losses in transmission and distribution brought down from around 17 per cent.

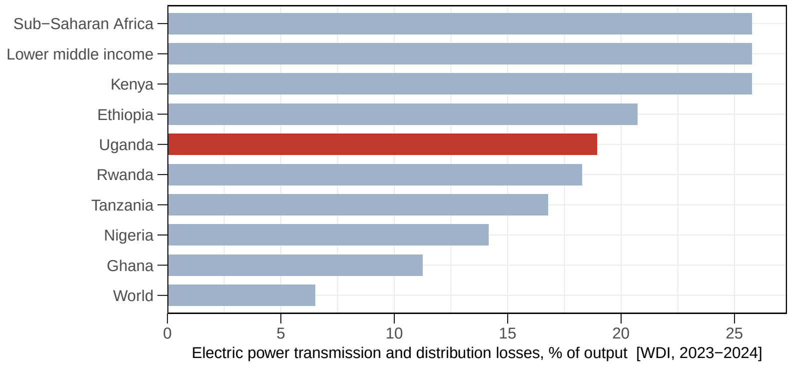

Figure 6.23: Uganda against its peers: Electric power transmission and distribution losses (% of output). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.12% in 2030 and +0.20% by 2040 against the balanced-growth baseline, and welfare by +0.09% and +0.15%. It ranks 7 of 7 in its group on GDP at 2040, the weakest.

6.2.6 Energy

In this run the strongest lever in Energy is **End-use energy efficiency** (+3.31% GDP, +3.16% welfare at 2040), while **Public energy spending** delivers the smallest GDP effect (-0.01%). The median lever in the group moves GDP by +0.17%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
End-use energy efficiency	+1.83	+3.31	+1.75	+3.16
Generation capacity	+0.18	+0.31	+0.14	+0.25
Rural electrification	+0.12	+0.20	+0.09	+0.15
Transmission and distribution	+0.10	+0.17	+0.07	+0.12
Renewable generation share	+0.08	+0.14	+0.06	+0.11
Fuel supply and refining	+0.01	+0.02	+0.01	+0.01
Public energy spending	-0.00	-0.01	+0.00	-0.01

Table 6.6: Energy: deviation from the balanced-growth baseline.

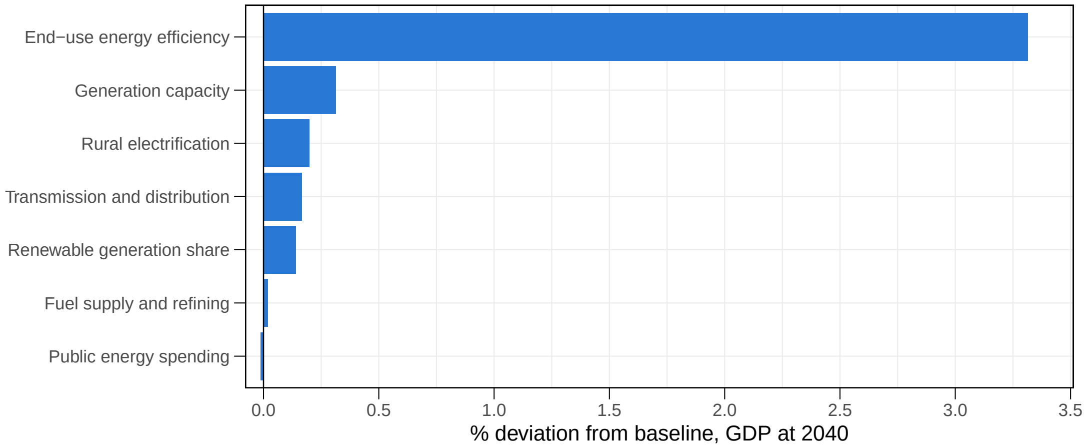

Figure 6.24: Energy: GDP deviation from baseline at 2040, by lever.

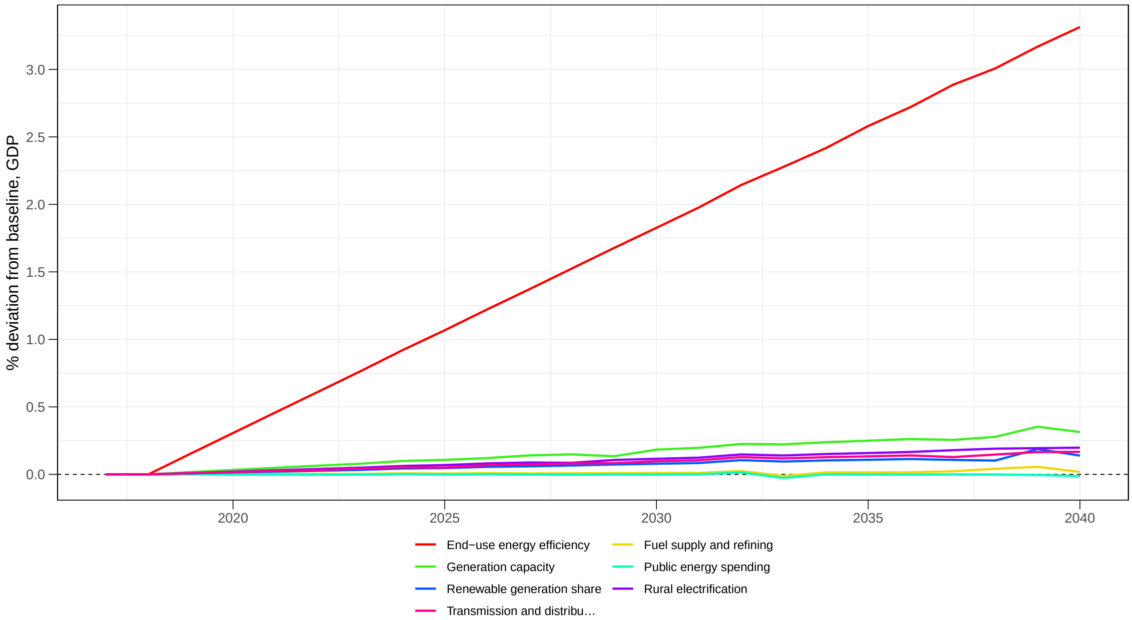

Figure 6.25: Energy: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

End-use energy efficiency. Solid biomass is about 90 per cent of Uganda's final energy consumption, and the 2024 census found only 3.8 per cent of households cooking with clean fuel [149, 125]. A three-stone fire uses 102 MJ to cook a kilogram of beans, an improved wood stove 39, an LPG stove 13 and an electric hot-plate 10 [252, 24]. The Fourth National Development Plan targets cutting biomass from 75 to 50 per cent of the energy mix by 2030, and government aims at five million households on clean cooking by then [241]. Efficiency of end use is therefore mostly a cooking question in Uganda, with industry's energy intensity a secondary channel.

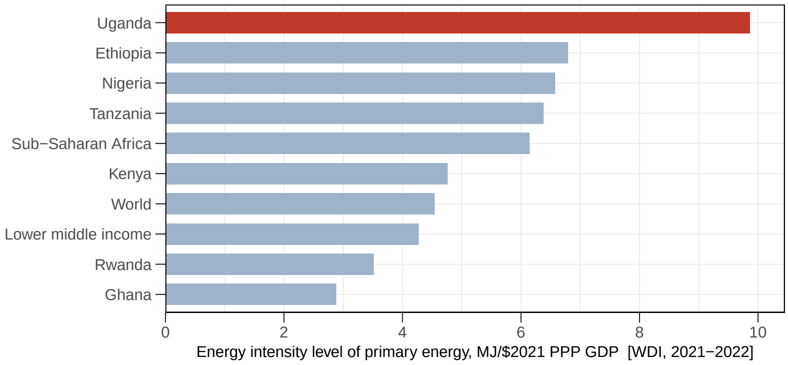

Figure 6.26: Uganda against its peers: Energy intensity level of primary energy (MJ/$2021 PPP GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +1.83% in 2030 and +3.31% by 2040 against the balanced-growth baseline, and welfare by +1.75% and +3.16%. It ranks 1 of 7 in its group on GDP at 2040, the strongest lever in the group.

Generation capacity. Uganda no longer has a generation deficit. Installed capacity rose from about 850 MW in 2014 to 2,098 MW at the end of 2025, with the 600 MW Karuma plant commissioned in June 2024, against a peak demand of about 1,350 MW; the country exports power to Kenya, Rwanda, Tanzania and the DRC [193, 108, 350]. The Electricity Regulatory Authority's own assessment is that the binding constraint has moved from generation to transmission, distribution and demand [109]. Consumption is still about 100 kWh per person a year, a tenth of the Sub-Saharan average, so this lever is best read as capacity that is used rather than capacity that is built.

The benchmark for this lever is Figure 6.17.

Result. In the model this lever moves GDP by +0.18% in 2030 and +0.31% by 2040 against the balanced-growth baseline, and welfare by +0.14% and +0.25%. It ranks 2 of 7 in its group on GDP at 2040.

Rural electrification. National electricity access reached 57 per cent in the latest UBOS household survey, 19 per cent on-grid and 38 per cent off-grid, but rural grid access is close to 11 per cent and the World Bank's project documents put the unconnected population at 58 per cent [39, 357]. The Electricity Access Scale-up Project finances low-cost densification, off-grid connections and clean cooking, and finds that even with subsidised connections a fifth of rural households cannot afford in-house wiring [359]. The 2018 Electricity Connection Policy has delivered about 300,000 free connections toward a 60 per cent target by 2027 [259]. Kenya, from a similar base in 2010, is now above 75 per cent.

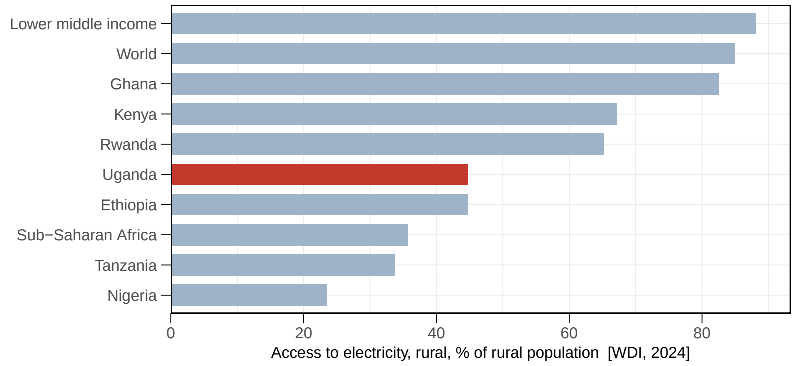

Figure 6.27: Uganda against its peers: Access to electricity, rural (% of rural population). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.12% in 2030 and +0.20% by 2040 against the balanced-growth baseline, and welfare by +0.09% and +0.15%. It ranks 3 of 7 in its group on GDP at 2040.

Transmission and distribution. Umeme's twenty-year distribution concession ended on 31 March 2025 with losses cut from 33 to about 16 per cent; UEDCL took over on 1 April [310, 352]. Transmission losses fell to 3.5 per cent in 2025, but distribution still loses about 19 per cent of energy purchased, and in its first year UEDCL logged 4,487 hours of outages costing an estimated UGX 12 billion, with 46 transmission-related interruptions in March 2026 alone [76, 279]. UEDCL has a US$994 million five-year grid master plan; UETCL carries UGX 1.48 trillion of unpaid bills [279, 315]. The lever is the productivity of the wires.

The benchmark for this lever is Figure 6.23.

Result. In the model this lever moves GDP by +0.10% in 2030 and +0.17% by 2040 against the balanced-growth baseline, and welfare by +0.07% and +0.12%. It ranks 4 of 7 in its group on GDP at 2040.

Renewable generation share. Uganda's grid is already among the cleanest in Africa: over 80 per cent of capacity is hydro, with bagasse co-generation, 60 MW of grid solar and 100 MW of thermal reserve [91, 107]. The GET FiT programme, run with KfW from 2013, financed 17 small hydro, solar and bagasse plants totalling about 156 MW by topping up the feed-in tariff and guaranteeing the off-taker [150, 170]. A revised solar feed-in tariff of US¢5.1 per kWh took effect in January 2026 [107]. The lever raises the renewable share further, which in Uganda's case means displacing thermal reserve and, more materially, the 90 per cent of final energy that is biomass.

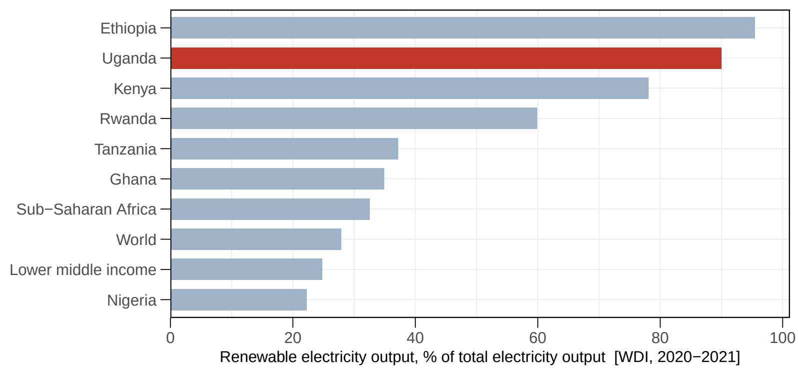

Figure 6.28: Uganda against its peers: Renewable electricity output (% of total electricity output). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.08% in 2030 and +0.14% by 2040 against the balanced-growth baseline, and welfare by +0.06% and +0.11%. It ranks 5 of 7 in its group on GDP at 2040.

Fuel supply and refining. Uganda imports all of its refined fuel, over US$2 billion a year [308]. The 60,000 barrel-a-day refinery at Kabaale in Hoima, a US$4 billion project in which Alpha MBM holds 60 per cent and the national oil company 40, is scheduled for commissioning in 2029–30 and is expected to displace about US$1.2 billion of product imports a year, producing petrol, diesel, LPG, kerosene, jet fuel and heavy fuel oil [313, 5, 110]. A products pipeline to Kampala is planned alongside it [351]. First crude from Tilenga and Kingfisher is expected in 2025–26. The lever models the productivity of the domestic fuel supply chain.

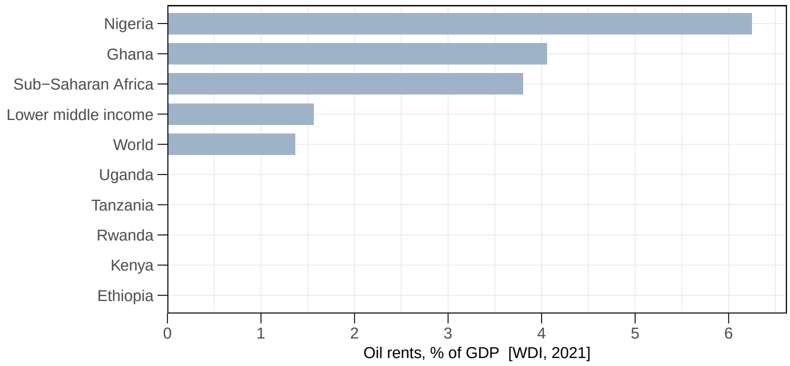

Figure 6.29: Uganda against its peers: Oil rents (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.01% in 2030 and +0.02% by 2040 against the balanced-growth baseline, and welfare by +0.01% and +0.01%. It ranks 6 of 7 in its group on GDP at 2040.

Public energy spending. The FY2026/27 budget allocates UGX 2.07 trillion to energy, for the 380 MW Kiba hydropower plant, floating solar at Isimba, 500 MW of utility solar in Elgon and Acholi, transmission lines, rural electrification and industrial connections [296, 295]. On top of that government spends over UGX 800 billion a year holding tariffs down, mainly for large industrial consumers [296]. SEforALL's analysis of access subsidies in Africa argues that the same money reaches more households through densification and off-grid support than through line extension [259]. The lever is an increase in public energy investment financed within the fiscal closure.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.01% by 2040 against the balanced-growth baseline, and welfare by +0.00% and -0.01%. It ranks 7 of 7 in its group on GDP at 2040, the weakest.

6.2.7 Transport infrastructure

In this run the strongest lever in Transport infrastructure is **Digital infrastructure** (+16.65% GDP, +15.69% welfare at 2040), while **Regional transport corridors** delivers the smallest GDP effect (+0.36%). The median lever in the group moves GDP by +4.19%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Digital infrastructure	+8.93	+16.65	+8.35	+15.69
Water and sanitation	+4.71	+8.61	+4.31	+8.03
Construction capacity	+4.23	+7.69	+4.09	+7.59
Logistics and freight services	+4.11	+7.63	+3.78	+6.88
Trunk roads	+0.38	+0.76	+0.94	+1.92
Ports and border efficiency	+0.26	+0.49	+0.65	+1.22
Rail freight	+0.24	+0.46	+0.80	+1.56
Regional transport corridors	+0.16	+0.36	+0.53	+1.15

Table 6.7: Transport infrastructure: deviation from the balanced-growth baseline.

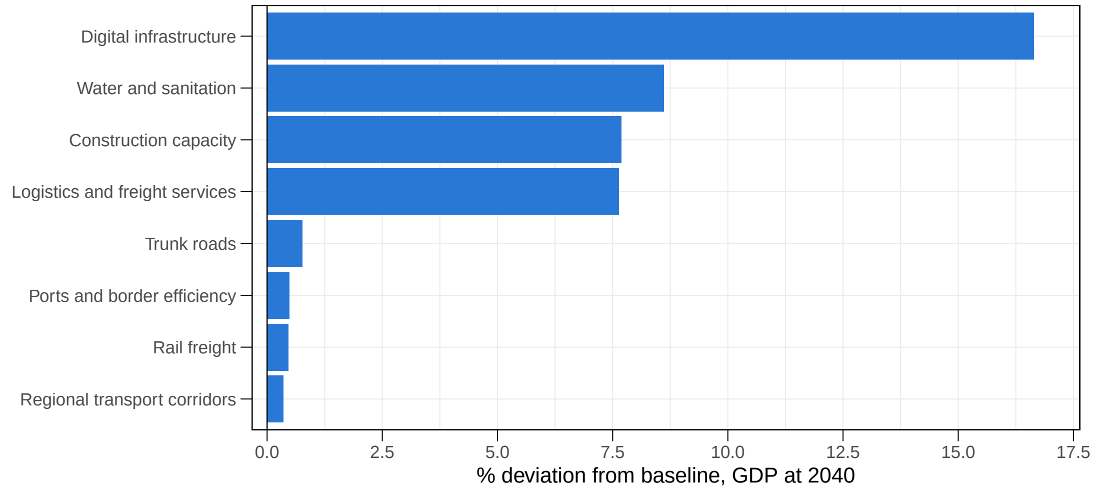

Figure 6.30: Transport infrastructure: GDP deviation from baseline at 2040, by lever.

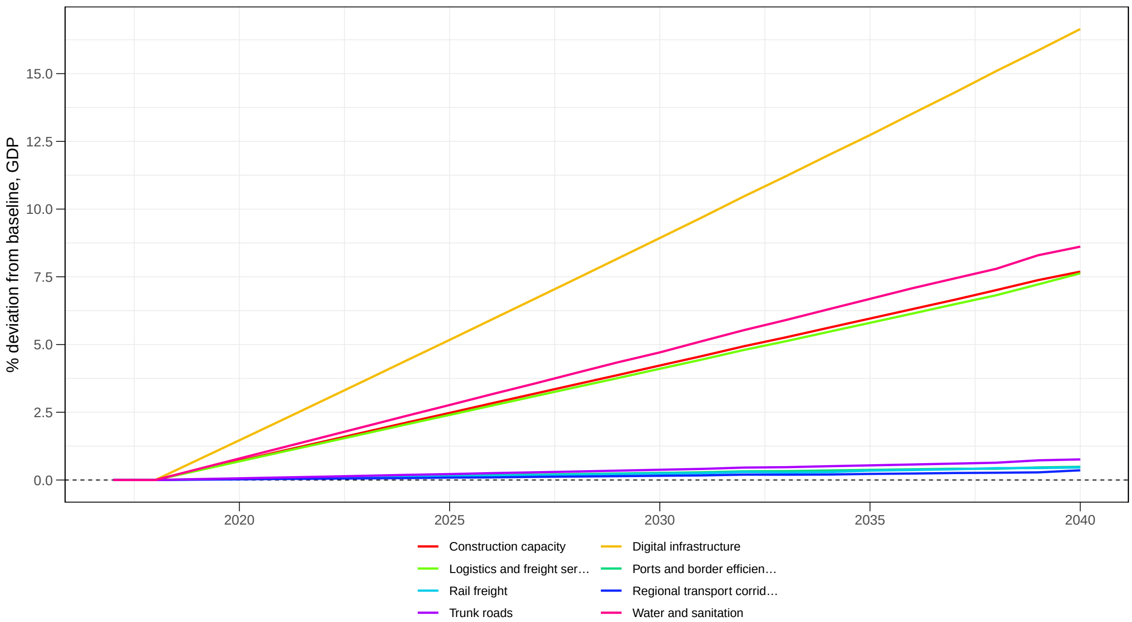

Figure 6.31: Transport infrastructure: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Digital infrastructure. Uganda's national backbone fibre, built by NITA-U, now reaches most district headquarters, and international capacity comes through Kenya and Tanzania [211]. Internet use is about 27 per cent of the population against 40 per cent in Kenya and a Sub-Saharan average near 37, and fixed broadband is negligible; mobile broadband is the access technology [376]. The Digital Transformation Roadmap 2023–2028 sets the targets for coverage and affordability [198]. The lever is the productivity of the telecommunications and data infrastructure, distinct from the adoption levers in the ICT group.

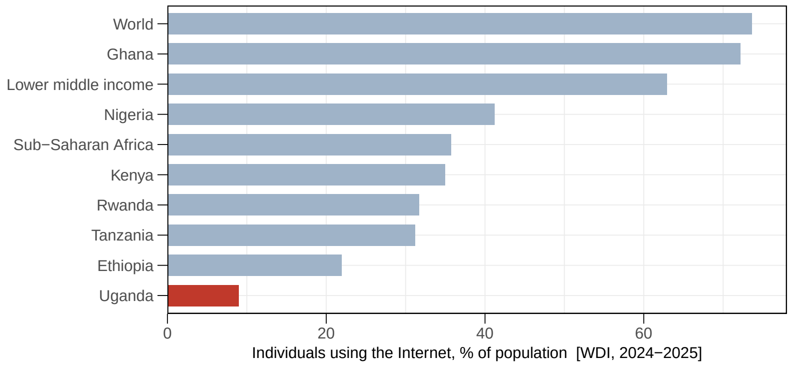

Figure 6.32: Uganda against its peers: Individuals using the Internet (% of population). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +8.93% in 2030 and +16.65% by 2040 against the balanced-growth baseline, and welfare by +8.35% and +15.69%. It ranks 1 of 8 in its group on GDP at 2040, the strongest lever in the group.

Water and sanitation. This lever, carried in the infrastructure group, is the utilities counterpart of the sector-specific water and sanitation levers reported later. Basic sanitation coverage is about 20 per cent of the population and basic drinking water about 60 per cent on WHO/UNICEF definitions, both below the Sub-Saharan average; the National Water and Sewerage Corporation serves the towns and loses about a third of the water it produces before it is billed [349, 212]. The lever is a productivity gain in the water-utilities sector as a whole.

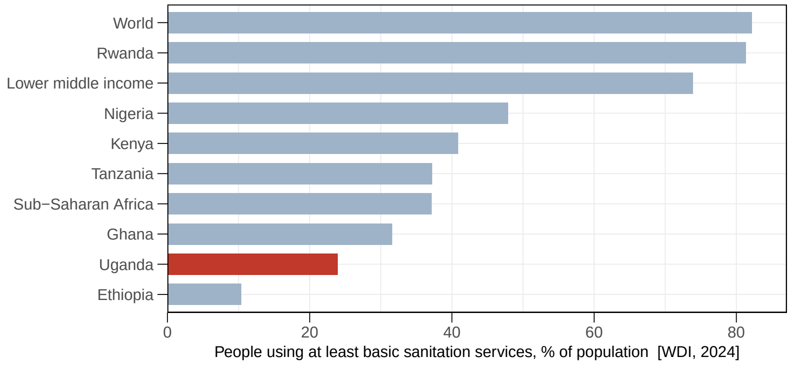

Figure 6.33: Uganda against its peers: People using at least basic sanitation services (% of population). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +4.71% in 2030 and +8.61% by 2040 against the balanced-growth baseline, and welfare by +4.31% and +8.03%. It ranks 2 of 8 in its group on GDP at 2040.

Construction capacity. Construction grew 11.6 per cent in FY2025 on public roads, oil-related works and housing, and the World Bank's 27th Uganda Economic Update treats it as the country's jobs engine for urban transformation [364]. Cement capacity has expanded quickly — Yaobai's 6,000 tonne-a-day clinker line and Moroto Cement at 3,000 — to the point that the Independent reports a glut [40, 272]. Quarterly construction value added is about UGX 2.9 trillion [287]. The lever models a productivity gain in the construction industry, which in a CGE lowers the cost of every investment good in the economy.

Result. In the model this lever moves GDP by +4.23% in 2030 and +7.69% by 2040 against the balanced-growth baseline, and welfare by +4.09% and +7.59%. It ranks 3 of 8 in its group on GDP at 2040.

Logistics and freight services. Uganda's overall logistics-performance score was about 2.5 of 5 in the last survey it entered, below Kenya, Rwanda and Tanzania [372, 288]. Two facilitation measures document what better freight services are worth: the Regional Electronic Cargo Tracking System cut Mombasa–Kampala transit for tracked consignments to 5.2 days against 7.3 for others, and replacing physical escorts saved US$400–500 per truck [286]; the Single Customs Territory removed duplicate clearance at each border [324]. The lever models a productivity gain in the freight-forwarding, trucking and warehousing services themselves rather than in the infrastructure they use.

Figure 6.34: Uganda against its peers: Logistics performance index: Overall (1=low to 5=high). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +4.11% in 2030 and +7.63% by 2040 against the balanced-growth baseline, and welfare by +3.78% and +6.88%. It ranks 4 of 8 in its group on GDP at 2040.

Trunk roads. Uganda has about 146,000 km of road, of which 21,544 km are national roads carrying over 80 per cent of traffic; some 5,600 km, about a quarter, are paved, and the Ministry of Works reports 97 per cent of paved and 82 per cent of unpaved national roads in fair-to-good condition [204, 185]. Maintenance is the recurring weakness identified in the national research repository [311]. The logistics-performance infrastructure score was 2.2 of 5 in 2018, below Kenya and Rwanda [373]. The lever is a productivity gain in road transport of the kind paving and maintenance deliver.

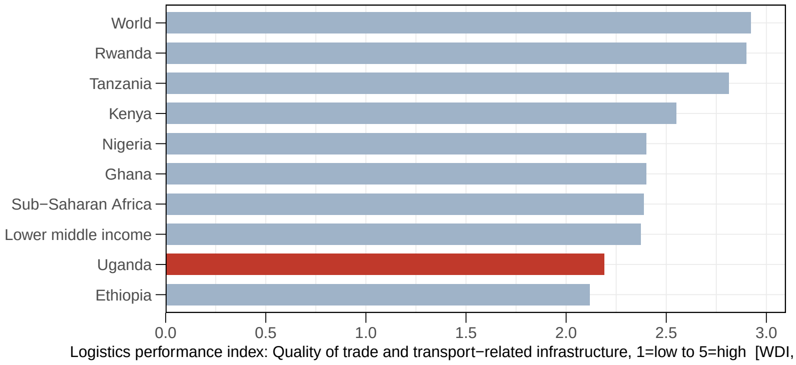

Figure 6.35: Uganda against its peers: Logistics performance index: Quality of trade and transport-related infrastructure (1=low to 5=high). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.38% in 2030 and +0.76% by 2040 against the balanced-growth baseline, and welfare by +0.94% and +1.92%. It ranks 5 of 8 in its group on GDP at 2040.

Ports and border efficiency. Uganda's sea gate is Mombasa. The Northern Corridor observatory reports transit from Mombasa to the Malaba and Busia border posts down from 109–114 hours in 2020 to 77–80 hours in 2022, still double the 40–45 hour target, with port dwell time under seven days against a 24-hour goal [222, 258]. Clearance at Malaba takes 4–8 hours when documents are in order and 2–3 days when they are not [184]. One-stop border posts across the EAC have cut crossing times by about 70 per cent and save an estimated US$63 million a year [96]. The lever is the productivity of the border and port link.

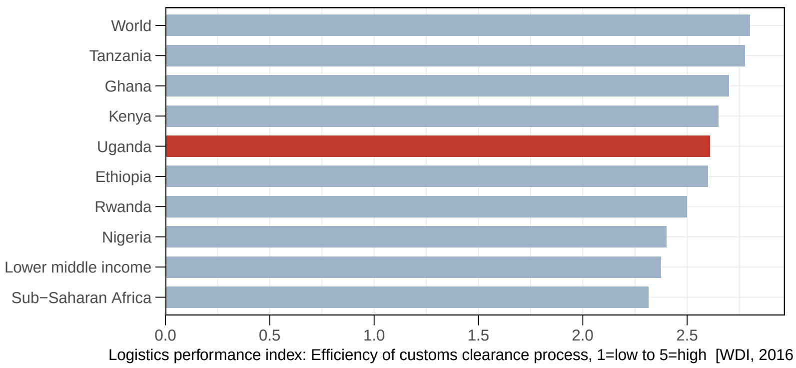

Figure 6.36: Uganda against its peers: Logistics performance index: Efficiency of customs clearance process (1=low to 5=high). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.26% in 2030 and +0.49% by 2040 against the balanced-growth baseline, and welfare by +0.65% and +1.22%. It ranks 6 of 8 in its group on GDP at 2040.

Rail freight. Of Uganda's 1,266 km metre-gauge network only about 265 km works: Kampala–Malaba, Port Bell and Kyengera [317]. The African Development Bank is financing refurbishment of the Malaba–Kampala line and the Tororo–Gulu line is being restored [7, 318]. In October 2024 government signed a EUR 2.7 billion contract with Yapı Merkezi for a 273 km electrified standard-gauge line from Malaba to Kampala, 25-tonne axle load, 120 km/h [242]. Freight by rail is a small fraction of the corridor's tonnage today; the lever models the cost reduction from moving bulk cargo off the road.

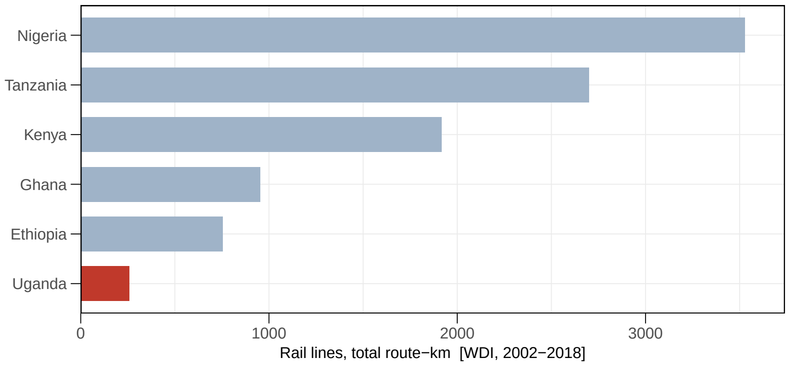

Figure 6.37: Uganda against its peers: Rail lines (total route-km). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.24% in 2030 and +0.46% by 2040 against the balanced-growth baseline, and welfare by +0.80% and +1.56%. It ranks 7 of 8 in its group on GDP at 2040.

Regional transport corridors. The Northern Corridor has been called the most expensive trade route in the world: Kampala–Mombasa cargo costs about US$2.5 per tonne-km equivalent against US$1.17 on Dar es Salaam–Kampala, and a container Mombasa–Kampala runs US$2,000–3,200 against a projected US$1,650 via the Central Corridor [264, 60, 54]. The East African Business Council puts regional logistics cost at US$1.8 per km per container [94]. A 2025 agreement between the two corridor authorities targets non-tariff barriers on both [266]. The lever models a fall in trade costs on the corridors that carry nearly all of Uganda's external trade.

Result. In the model this lever moves GDP by +0.16% in 2030 and +0.36% by 2040 against the balanced-growth baseline, and welfare by +0.53% and +1.15%. It ranks 8 of 8 in its group on GDP at 2040, the weakest.

6.2.8 Services

In this run the strongest lever in Services is **Tourism expansion** (+8.71% GDP, +8.24% welfare at 2040), while **Trade facilitation** delivers the smallest GDP effect (+0.41%). The median lever in the group moves GDP by +6.40%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Tourism expansion	+4.74	+8.71	+4.38	+8.24
Financial inclusion	+3.84	+7.15	+3.53	+6.43
Transport services	+3.78	+6.91	+3.48	+6.44
ICT and business services	+3.23	+5.89	+2.96	+5.42
Retail and wholesale modernisation	+2.92	+5.32	+2.67	+4.73
Trade facilitation	+0.22	+0.41	+0.55	+1.04

Table 6.8: Services: deviation from the balanced-growth baseline.

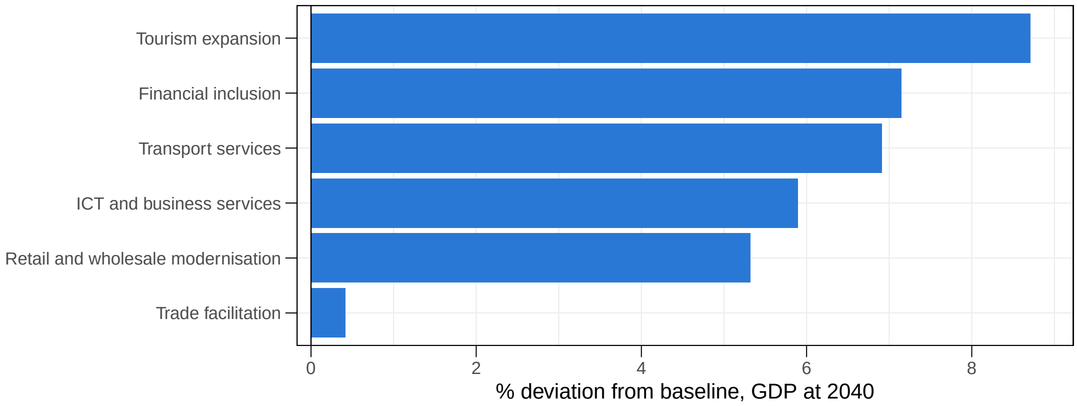

Figure 6.38: Services: GDP deviation from baseline at 2040, by lever.

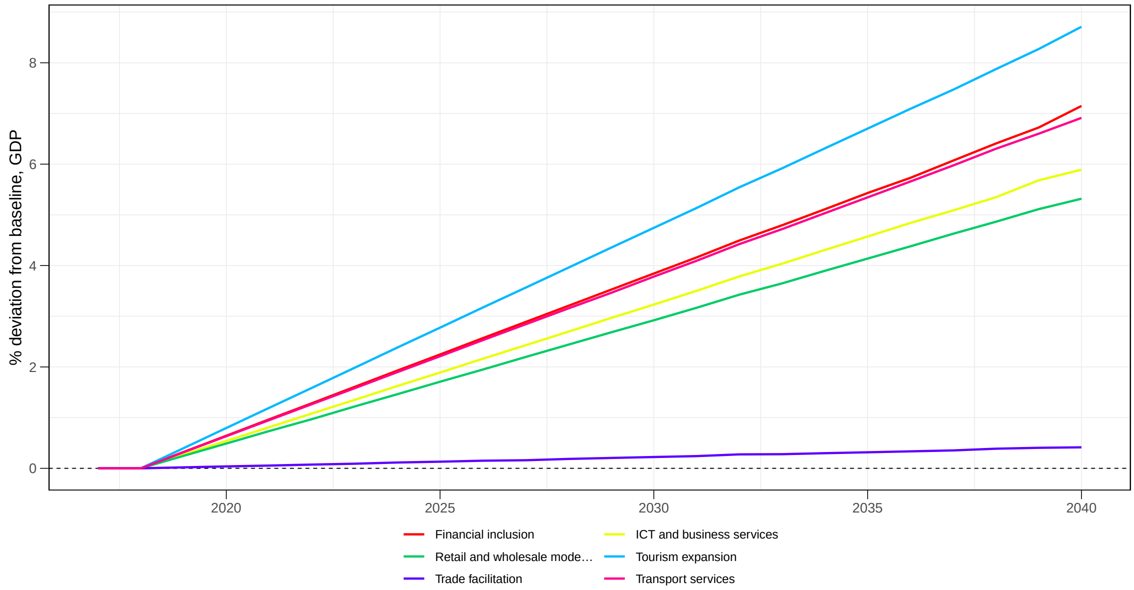

Figure 6.39: Services: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Tourism expansion. Tourism receipts reached a record US$1.28 billion in 2024, up 25.9 per cent, on 1.37 million arrivals; visitors stayed 8.7 nights and spent US$125 a day [201, 257]. The sector is about 6.6 per cent of GDP and 7.2 per cent of employment, and receipts are 16 per cent of total exports, though arrivals are still below the 2019 peak [194, 37]. Kenya and Tanzania each earn two to three times as much from tourism. The lever is a productivity gain in the accommodation, food and recreation activities that tourism spending lands on.

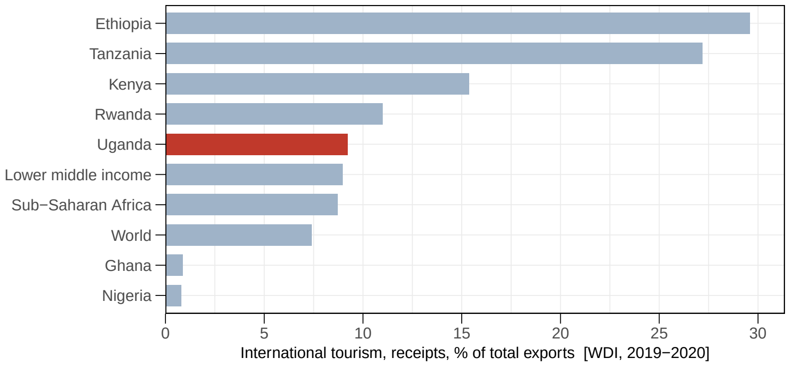

Figure 6.40: Uganda against its peers: International tourism, receipts (% of total exports). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +4.74% in 2030 and +8.71% by 2040 against the balanced-growth baseline, and welfare by +4.38% and +8.24%. It ranks 1 of 6 in its group on GDP at 2040, the strongest lever in the group.

Financial inclusion. FinScope 2023 finds 81 per cent of Ugandan adults using formal or informal financial services, up from 77 per cent in 2018; mobile money use rose from 56 to 64 per cent, SACCO use from 5 to 14, and saving by phone doubled to 42 per cent [120, 271]. Formal account ownership is 61 per cent in rural areas against 73 in towns, and only 22 per cent of the adults in agriculture have accessed finance for it [64]. The National Financial Inclusion Strategy 2023–2028 targets the rural and credit gaps [28]. Kenya's Findex account ownership is about 79 per cent against Uganda's 66. The lever is the productivity of financial intermediation.

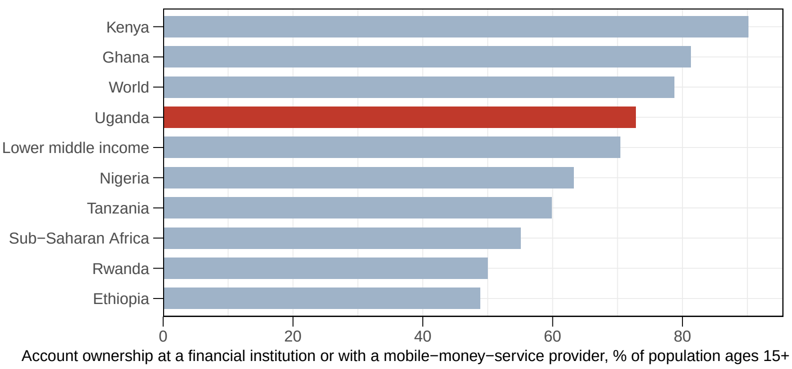

Figure 6.41: Uganda against its peers: Account ownership at a financial institution or with a mobile-money-service provider (% of population ages 15+). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +3.84% in 2030 and +7.15% by 2040 against the balanced-growth baseline, and welfare by +3.53% and +6.43%. It ranks 2 of 6 in its group on GDP at 2040.

Transport services. Transport services in Uganda are road haulage, matatu and boda-boda passenger transport, and the freight-forwarding trade at the Kampala end of the Northern Corridor. The corridor observatory's cost figures — US$2,000–2,700 for a container Mombasa to Kampala, the highest in the EAC — are as much a measure of the trucking market as of the road [60, 221]. The Northern Corridor authority calls high transport rates the silent killer of trade on the route [221]. The lever is a productivity gain in the transport-services activity itself.

The benchmark for this lever is Figure 6.34.

Result. In the model this lever moves GDP by +3.78% in 2030 and +6.91% by 2040 against the balanced-growth baseline, and welfare by +3.48% and +6.44%. It ranks 3 of 6 in its group on GDP at 2040.

ICT and business services. Uganda's business-process outsourcing and IT-services sector counts 48 registered firms employing about 4,000 people, growing around 30 per cent a year, with a 240-seat public incubation centre in Kampala [209]. The National BPO Policy of 2025 and the BPO and IT Services Job Creation Strategy target 100,000 jobs by 2030 on the strength of English, cost and time zone [200, 199]. Kenya's sector is an order of magnitude larger. The lever is a productivity gain in business services, the intermediate-input sector that every other industry buys from.

Result. In the model this lever moves GDP by +3.23% in 2030 and +5.89% by 2040 against the balanced-growth baseline, and welfare by +2.96% and +5.42%. It ranks 4 of 6 in its group on GDP at 2040.

Retail and wholesale modernisation. Wholesale and retail trade is about 18 per cent of Uganda's GDP and employs some 1.2 million people, and it is overwhelmingly informal: open-air markets, kiosks and dukas remain the main outlets, especially outside Kampala [344, 319]. Formal retail — Capital Shoppers, Quality, Mega Standard, Carrefour — serves the urban middle and upper income segments [344]. The World Bank's study of distribution services in East Africa argues that modern distribution lowers consumer prices and farm-gate margins alike once it reaches scale [365]. The lever is a productivity gain in the trade sector, which in a CGE is a fall in the margin between producer and consumer prices.

Result. In the model this lever moves GDP by +2.92% in 2030 and +5.32% by 2040 against the balanced-growth baseline, and welfare by +2.67% and +4.73%. It ranks 5 of 6 in its group on GDP at 2040.

Trade facilitation. The EAC's facilitation measures have measurable returns for Uganda: the Single Customs Territory clears goods once at destination; the Regional Electronic Cargo Tracking System cut tracked transit times by two days; one-stop border posts have reduced crossing times by about 70 per cent [324, 286, 96]. The US International Trade Commission's review of EAC trade facilitation finds the remaining costs in documentation, weighbridges and roadblocks rather than tariffs [294]. Trade is about 45 per cent of GDP. The lever models a further fall in the non-tariff cost of trading across Uganda's borders.

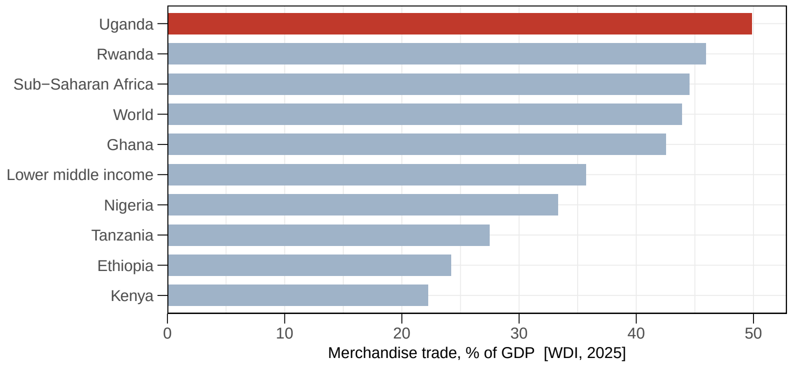

Figure 6.42: Uganda against its peers: Merchandise trade (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.22% in 2030 and +0.41% by 2040 against the balanced-growth baseline, and welfare by +0.55% and +1.04%. It ranks 6 of 6 in its group on GDP at 2040, the weakest.

6.2.9 Health

In this run the strongest lever in Health is **Population health and nutrition** (+1.02% GDP, +1.01% welfare at 2040), while **Health service delivery — spend MORE** delivers the smallest GDP effect (-0.00%). The median lever in the group moves GDP by +0.00%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Where Uganda's health outcomes stand

Figure 6.43 sets the three health levers against the outcomes that health spending is meant to move. Uganda's maternal mortality ratio fell from 475 per 100,000 live births in 2000 to 170 in 2023; infant mortality from 89 to 36 per 1,000 live births (2024); under-five mortality from 144 to 49 [380]. Those are large declines, and they track the regional trend rather than lead it: Kenya's maternal ratio is 149, Rwanda's 229, the Sub-Saharan average 448 and the world's 197; on infant mortality Uganda's 36 compares with 34 in Kenya, 29 in Rwanda, 47 for the region and 28 for the world.

The chart is the case for the third lever. Rwanda spends more per head than Uganda but not several times more, and reaches a maternal ratio less than half of Uganda's; the difference is in how the money is turned into delivery — staffing, drugs on the shelf, referral — which is what the *spend better* lever models and what the stock-out and absenteeism evidence cited under it describes. The *spend more* lever, by contrast, adds money at today's conversion rate.

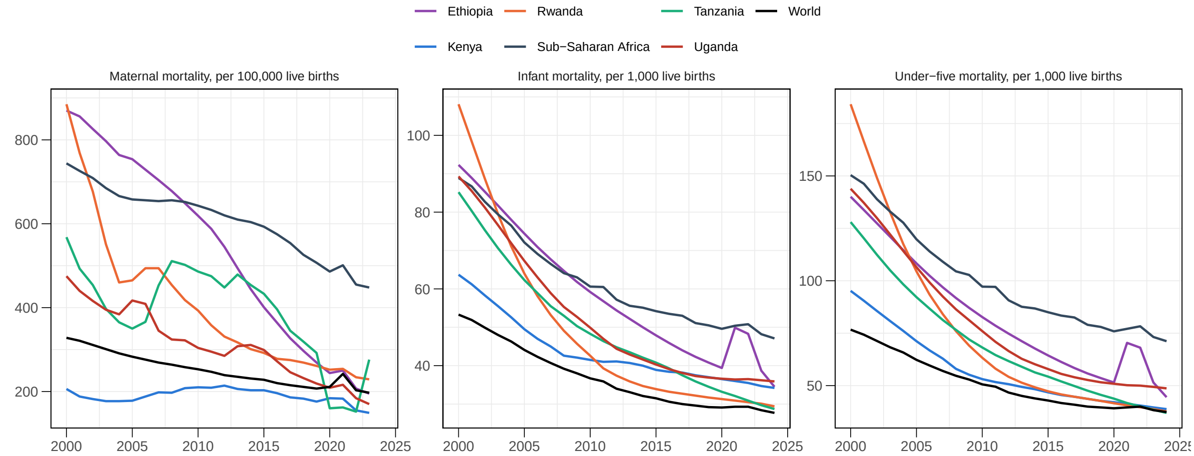

Figure 6.43: Maternal, infant and under-five mortality, 2000 to the latest year: Uganda, peers, the Sub-Saharan and world aggregates (WDI; WHO and UN IGME estimates).

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Population health and nutrition	+0.29	+1.02	+0.29	+1.01
Health system effectiveness — spend BETTER	+0.00	+0.00	+0.00	+0.00
Health service delivery — spend MORE	-0.00	-0.00	+0.01	+0.01

Table 6.9: Health: deviation from the balanced-growth baseline.

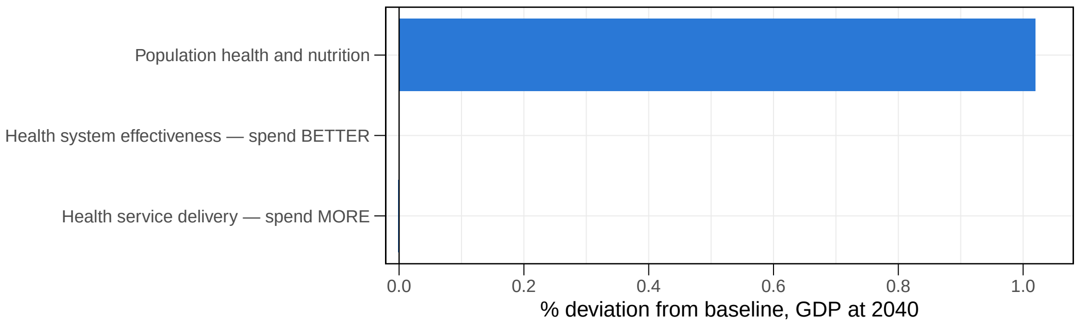

Figure 6.44: Health: GDP deviation from baseline at 2040, by lever.

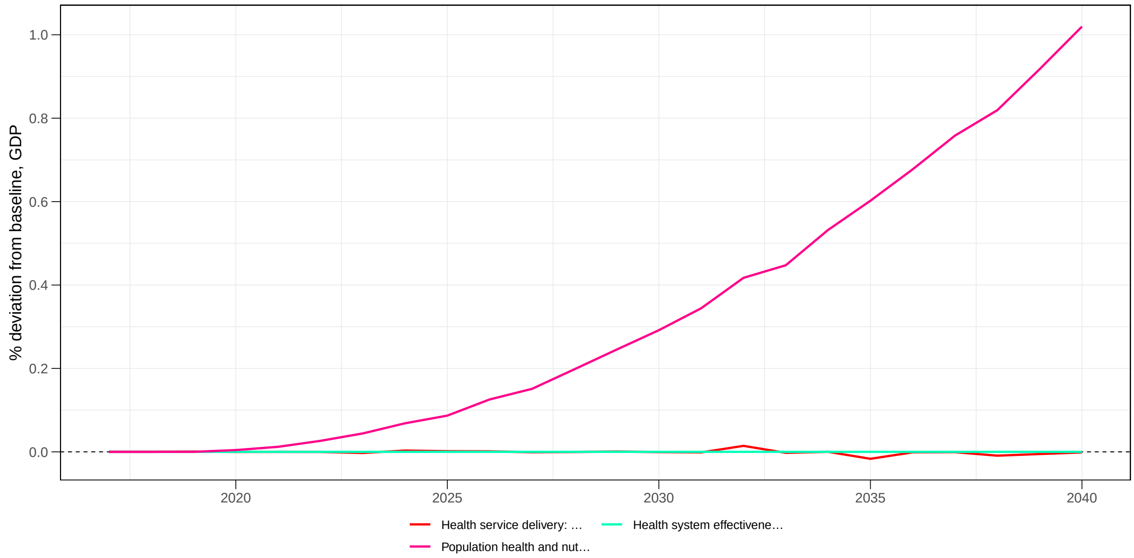

Figure 6.45: Health: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Population health and nutrition. The 2022 Demographic and Health Survey puts stunting among under-fives at 26 per cent, down from 29 in 2016, with wasting steady near 4 per cent; Karamoja (44 per cent), Kigezi (42) and Tooro (39) are the worst regions [73, 129]. Uganda is off track for the World Health Assembly stunting target by about five points [129]. Tanzania has cut stunting over thirty years by roughly a point a year through the same channels — maternal education, complementary feeding, water — that the Ugandan cohort studies identify [236, 233]. The lever models the labour-productivity gain from a healthier, better-nourished workforce.

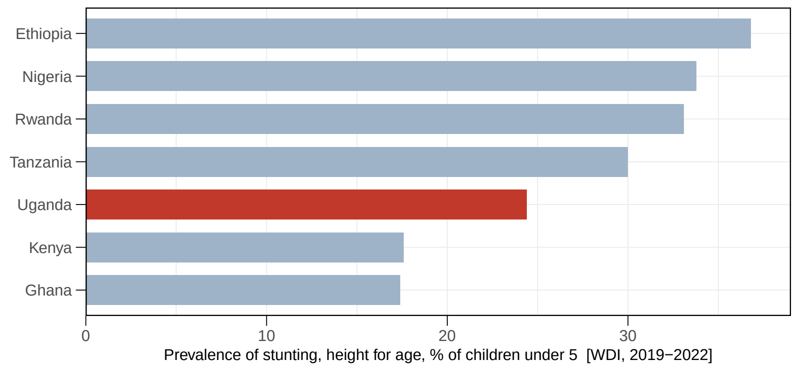

Figure 6.46: Uganda against its peers: Prevalence of stunting, height for age (% of children under 5). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.29% in 2030 and +1.02% by 2040 against the balanced-growth baseline, and welfare by +0.29% and +1.01%. It ranks 1 of 3 in its group on GDP at 2040, the strongest lever in the group.

Health system effectiveness — spend BETTER. The evidence that Uganda's health system could deliver more from the same money is direct. Eighty-four per cent of facilities reported stock-outs of essential medicines in the previous six months, driven by demand surges, late deliveries and order discrepancies [167]; district performance reviews in the Mbale region found staffing shortages in 91 per cent of districts and excessive absenteeism in 73 [247]. Uganda's subnational health-systems functionality index correlates with UHC outcomes at 64 per cent, with access the strongest domain and resilience the weakest [246]. The SPARS supervision programme shows medicines management improves measurably when supervised [165]. The lever raises the productivity of health services at constant spending.

Figure 6.47: Uganda against its peers: Life expectancy at birth, total (years). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.00% in 2030 and +0.00% by 2040 against the balanced-growth baseline, and welfare by +0.00% and +0.00%. It ranks 2 of 3 in its group on GDP at 2040.

Health service delivery — spend MORE. Government health spending is 6–10 per cent of the budget against the 15 per cent Abuja commitment, and UNICEF's FY2025/26 budget brief puts the public health budget at about US$23 per person against the US$28 the Health Financing Strategy costed a decade ago and far below the WHO's benchmark [338, 83]. Public health expenditure is about 1 per cent of GDP against 2 in Kenya and 3 in Rwanda [283]. Out-of-pocket payments carry a large share of the rest and the financing is regressive [8]. This lever raises public health spending with the same delivery efficiency; the next lever holds spending and raises efficiency.

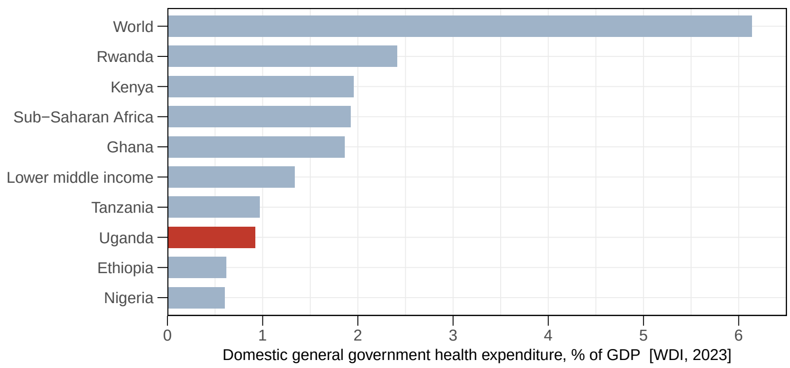

Figure 6.48: Uganda against its peers: Domestic general government health expenditure (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.00% by 2040 against the balanced-growth baseline, and welfare by +0.01% and +0.01%. It ranks 3 of 3 in its group on GDP at 2040, the weakest. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

6.2.10 Education

In this run the strongest lever in Education is **Skills upgrading** (+2.35% GDP, +2.34% welfare at 2040), while **Primary education spending** delivers the smallest GDP effect (-0.01%). The median lever in the group moves GDP by +0.06%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Where Uganda's enrolment stands

Figures 6.49 and 6.50 set the education levers against the enrolment record. Uganda's primary gross enrolment ratio is 119.5 per cent in the 2023/24 National Household Survey, up from 116.8 in 2016/17 — above 100 because over-age and repeating pupils are counted against the official age cohort — against a Sub-Saharan average near 97 [215, 300, 381]. Secondary is where the gap opens: the gross ratio *fell* from 37.9 to 33.6 per cent between the two surveys and the net rate from 27.8 to 23.2 per cent, with 46.9 per cent gross in towns against 26.0 in the countryside [215, 192]. Kenya's secondary gross ratio is about 84 per cent (2023), Rwanda's 49 (2024) and the regional average 46 [381]. Tertiary gross enrolment was 4.6 per cent when Uganda last reported it (2014) against 10 in Kenya and 9 in Rwanda today.

The reading for the levers is direct. Primary spending acts on a system that already enrols everyone but keeps fewer than a third of them to P7; its return is completion and learning, not access. Secondary spending acts on a rate that is a quarter and falling, so it is the lever with the widest gap between Uganda and its peers, and the one for which the model's skilled-labour channel has the most headroom. Uganda has not reported gross and net ratios to UNESCO since 2017, which is why the international series stop there and the household-survey points are plotted separately.

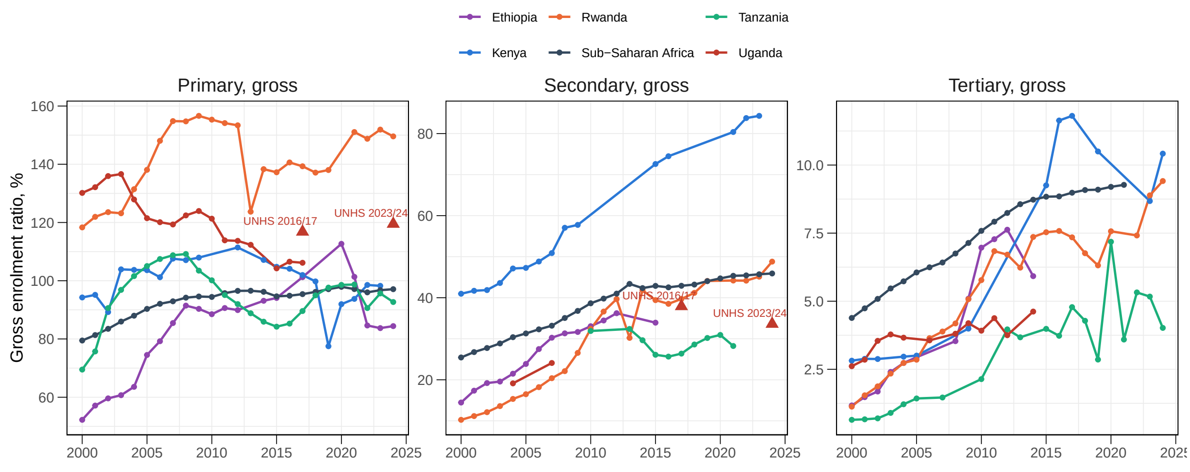

Figure 6.49: Gross enrolment ratios, primary, secondary and tertiary: Uganda and peers (WDI/UIS) with the UNHS 2016/17 and 2023/24 national points.

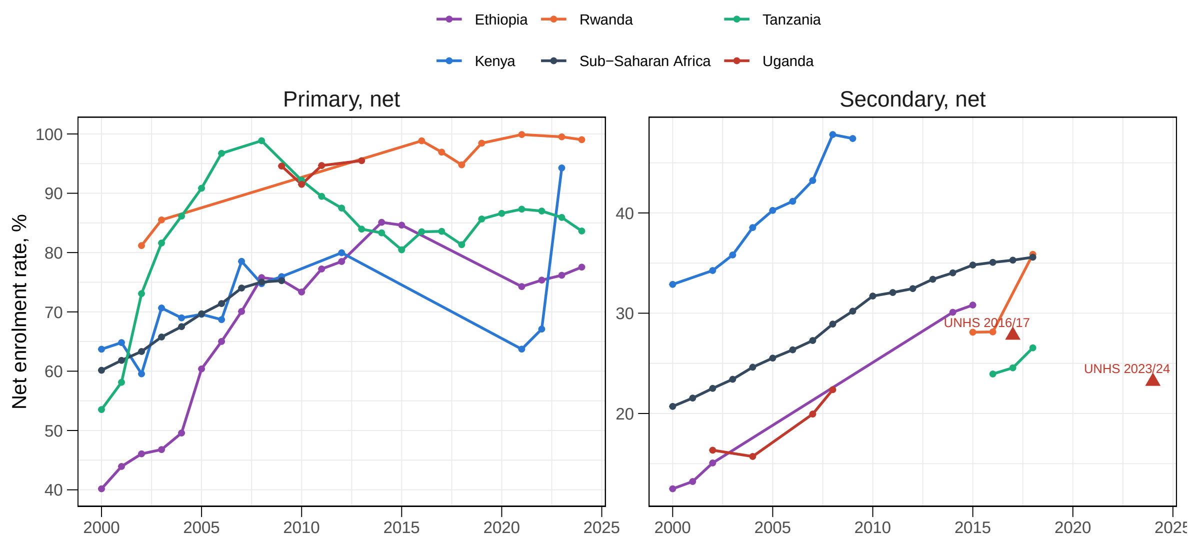

Figure 6.50: Net enrolment rates, primary and secondary: Uganda and peers (WDI/UIS) with the UNHS national points.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Skills upgrading	+0.66	+2.35	+0.65	+2.34
TVET expansion	+0.44	+1.57	+0.44	+1.57
School completion	+0.36	+1.24	+0.36	+1.24
Education spending, all cycles	-0.00	+0.06	+0.03	+0.19
Tertiary education spending	-0.00	-0.00	+0.00	+0.01
Secondary education spending	+0.00	-0.00	+0.01	+0.01
Primary education spending	-0.00	-0.01	+0.01	+0.01

Table 6.10: Education: deviation from the balanced-growth baseline.

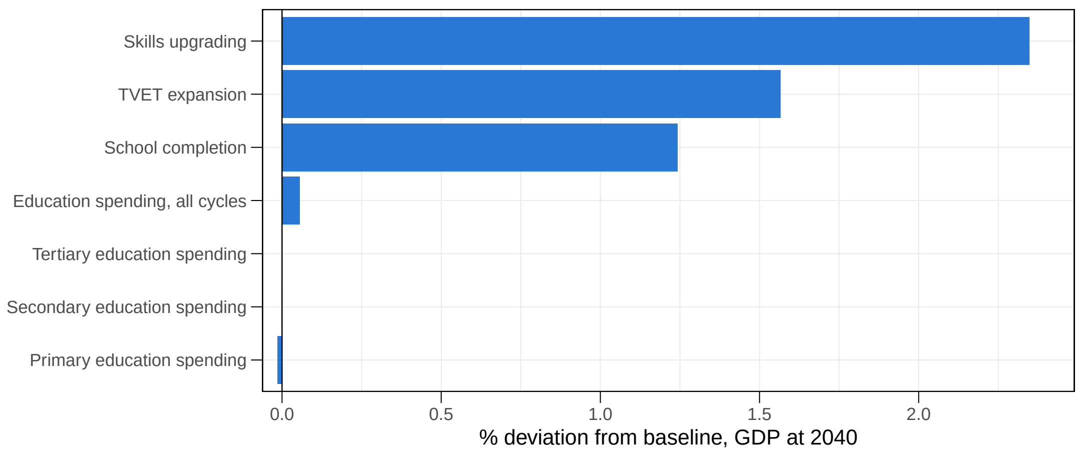

Figure 6.51: Education: GDP deviation from baseline at 2040, by lever.

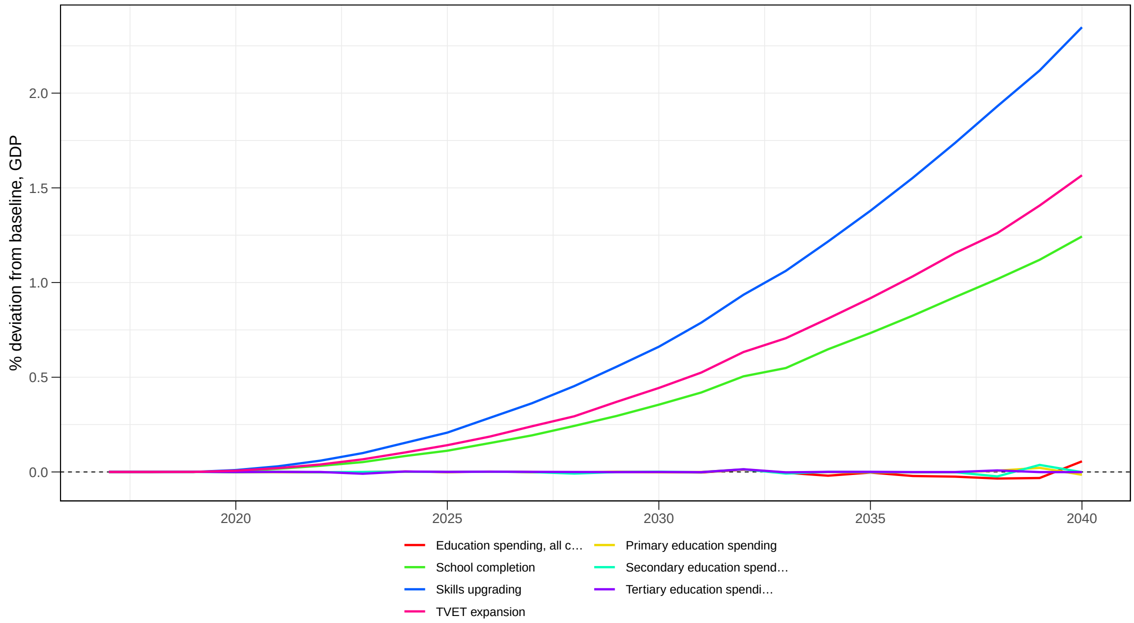

Figure 6.52: Education: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Skills upgrading. The 2016/17 Manpower Survey found employers most short of managerial (22 per cent) and customer-care (19 per cent) skills, with IT and communication the most cited gaps among professionals [297]. The 2021 Labour Force Survey counts 7.2 million in informal non-household work against 2.2 million formal jobs; youth unemployment is 17.9 per cent and 42.6 per cent of 15–24 year olds are not in employment, education or training [298, 274]. The Economic Policy Research Centre's review of Skilling Uganda, the Skills Development Project and the Youth Livelihood Programme finds the mismatch persisting through all three [105]. The lever shifts labour from the unskilled to the skilled pool.

Result. In the model this lever moves GDP by +0.66% in 2030 and +2.35% by 2040 against the balanced-growth baseline, and welfare by +0.65% and +2.34%. It ranks 1 of 7 in its group on GDP at 2040, the strongest lever in the group.

TVET expansion. Uganda's technical and vocational system rests on the BTVET Act of 2008, the Skilling Uganda strategic plan and the TVET Policy of 2019, replaced by a TVET Act in 2025 that moves to employer-led, competency-based training [332, 190]. The World Bank's US$100 million Uganda Skills Development Project financed the reforms until it closed in 2021, and institutions have since asked government to restore cost-sharing as training costs rise [191, 82]. Kim's analysis finds the system still small relative to the cohort and weakly linked to employers [162]. The lever expands vocational training as a route into the skilled labour pool.

Result. In the model this lever moves GDP by +0.44% in 2030 and +1.57% by 2040 against the balanced-growth baseline, and welfare by +0.44% and +1.57%. It ranks 2 of 7 in its group on GDP at 2040.

School completion. Uganda's paradox is high entry and high drop-out. Universal primary education lifted enrolment from 3.1 million in 1996 to 7.6 million in 2003, but survival to P7 has averaged about 30 per cent for a decade — 32 per cent of the 2008 cohort finished in 2014 — and the share of 14-year-olds who had reached P7 fell from 13 to 10 per cent between 2020 and 2024 [75, 333, 331]. Studies of who leaves find the predictors differ between town and country and that institutional quality of the school matters for retention [158, 159]. The lever raises completion at given spending, which in the model is a rise in the share of the cohort entering the skilled pool.

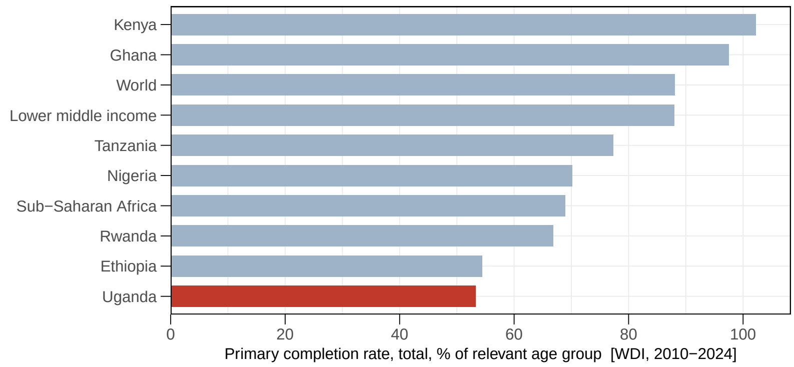

Figure 6.53: Uganda against its peers: Primary completion rate, total (% of relevant age group). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.36% in 2030 and +1.24% by 2040 against the balanced-growth baseline, and welfare by +0.36% and +1.24%. It ranks 3 of 7 in its group on GDP at 2040.

Education spending, all cycles. Uganda spends 2.5–2.7 per cent of GDP on public education against 3.3 in Tanzania, 3.8 in Rwanda and 4.8 in Kenya, and below the 4 per cent floor of the Education 2030 framework [66, 336]. As a share of the budget the gap is the same: about 10–11 per cent against Kenya's 23 and Tanzania's 17 [334, 375]. The World Bank has said plainly that Uganda's education expenditure is far below its neighbours' [66]. The lever raises spending across all cycles at once, so its result is the sum of the primary, secondary and tertiary levers' channels.

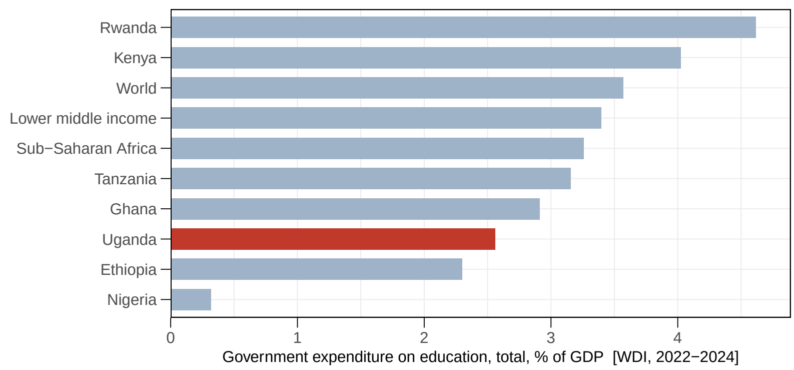

Figure 6.54: Uganda against its peers: Government expenditure on education, total (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by -0.00% in 2030 and +0.06% by 2040 against the balanced-growth baseline, and welfare by +0.03% and +0.19%. It ranks 4 of 7 in its group on GDP at 2040.

Tertiary education spending. Tertiary enrolment rose from 365,000 in 2021 to 485,000 in 2023 across 1,459 institutions, 449 public and 1,010 private, and graduate output from 182,000 to 241,000 [274]. The National Planning Authority estimates 700,000 entrants to the labour market each year against about 90,000 jobs [55]. Employer surveys find graduates strong on theory and short of practical, behavioural and digital skills [157, 254]. Gross tertiary enrolment is about 6 per cent against 10–12 in Kenya and Ghana. The lever raises tertiary spending and thus the supply of skilled labour.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.00% by 2040 against the balanced-growth baseline, and welfare by +0.00% and +0.01%. It ranks 5 of 7 in its group on GDP at 2040. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

Secondary education spending. Net secondary enrolment is about 23 per cent and the gross attendance ratio 39 per cent against 49 among regional peers [67, 378]. Universal secondary education from 2007 raised gross enrolment 28 per cent in two years, and secondary schools grew from 2,373 to 3,000 by 2017 [189, 163]. Transition from primary is the bottleneck — the World Bank finds only 60 per cent of entrants still in school at the end of P7, with cost the most common reason [67]. The Economic Policy Research Centre documents the girl-child enrolment gap [100]. The lever raises secondary spending, which in the model shifts labour toward the skilled pool.

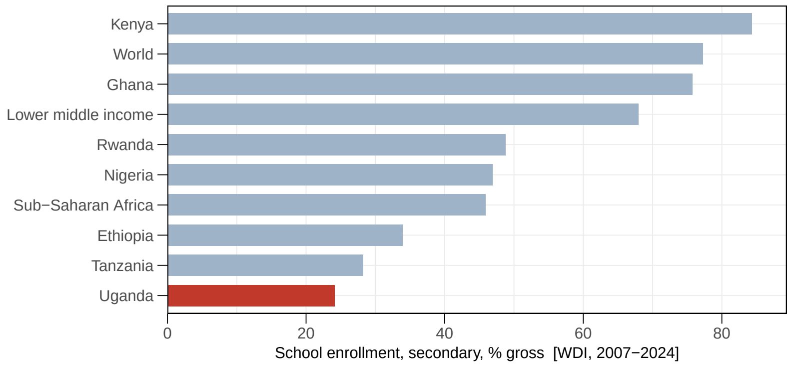

Figure 6.55: Uganda against its peers: School enrollment, secondary (% gross). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.00% in 2030 and -0.00% by 2040 against the balanced-growth baseline, and welfare by +0.01% and +0.01%. It ranks 6 of 7 in its group on GDP at 2040. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

Primary education spending. The capitation grant for primary pupils is UGX 18,000 a year (about US$4.75) in 2025/26 [336]. Learning outcomes are the concern: 50 per cent literacy at P3 and 53 at P6, 55 and 51 per cent numeracy, with Kampala 30–40 points ahead of the poorest regions [4, 140]. Uwezo's analysis of its household assessments shows maternal education the strongest single predictor of whether a child can read [140]. UNESCO's 2026 GEM country study reviews the system's completion and foundational-learning record [331]. The lever raises public spending on primary education, which in the model builds human capital in the unskilled labour pool.

The benchmark for this lever is Figure 6.53.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.01% by 2040 against the balanced-growth baseline, and welfare by +0.01% and +0.01%. It ranks 7 of 7 in its group on GDP at 2040, the weakest. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

6.2.11 ICT and the digital economy

In this run the strongest lever in ICT and the digital economy is **Economy-wide digital adoption** (+8.31% GDP, +8.06% welfare at 2040), while **Electronic single window** delivers the smallest GDP effect (+0.28%). The median lever in the group moves GDP by +6.13%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Economy-wide digital adoption	+4.46	+8.31	+4.27	+8.06
Mobile money and digital payments	+3.84	+7.15	+3.53	+6.43
Broadband coverage	+3.45	+6.37	+3.18	+6.01
IT services and outsourcing	+3.23	+5.89	+2.96	+5.42
Digital government and e-services	+2.62	+4.76	+2.40	+4.36
Electronic single window	+0.15	+0.28	+0.37	+0.70

Table 6.11: ICT and the digital economy: deviation from the balanced-growth baseline.

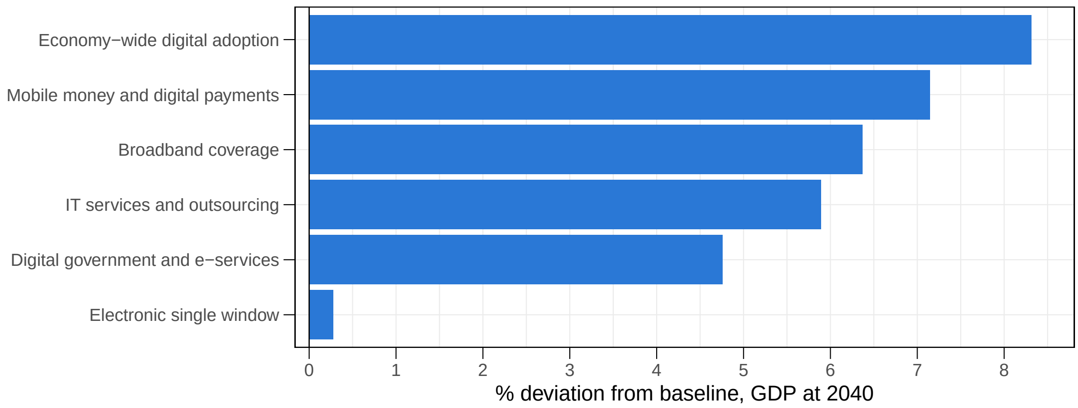

Figure 6.56: ICT and the digital economy: GDP deviation from baseline at 2040, by lever.

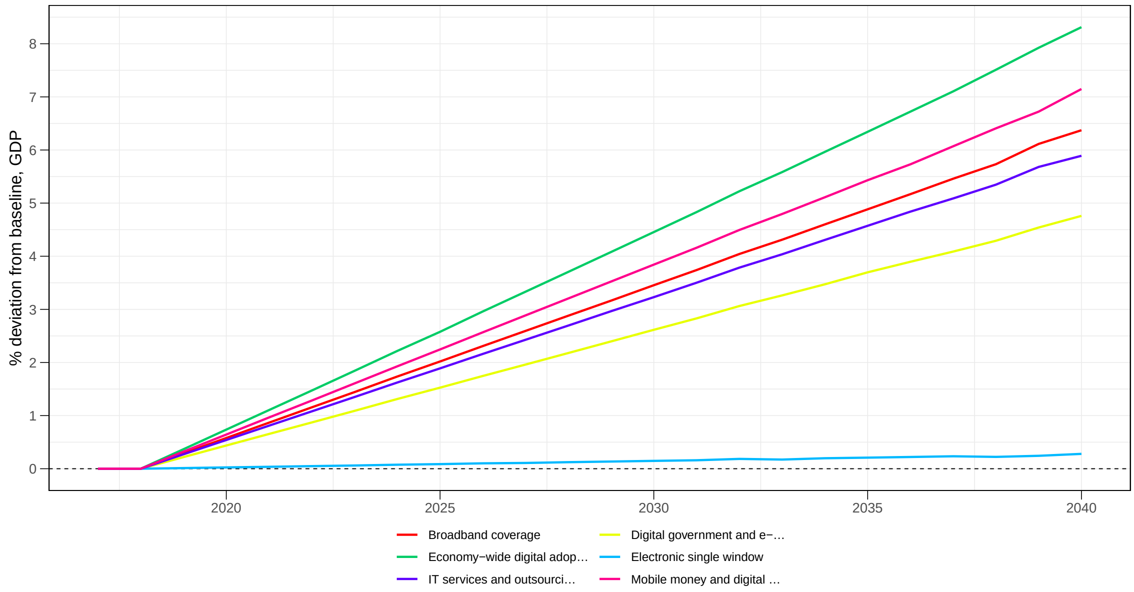

Figure 6.57: ICT and the digital economy: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Economy-wide digital adoption. About 55 per cent of Ugandan businesses have internet access, 33 per cent a website and roughly half use online tools for transactions; the gains concentrate in better-resourced firms, held back by digital literacy, data cost and managerial awareness [103, 154]. MSMEs employ over 2.5 million people and are about 20 per cent of GDP [244]. Firm-level studies of ICT adoption find specialised skills and outsourcing of ICT functions the key barriers [1]. The lever is a productivity gain across all sectors from digital adoption, the broadest of the ICT levers.

The benchmark for this lever is Figure 6.32.

Result. In the model this lever moves GDP by +4.46% in 2030 and +8.31% by 2040 against the balanced-growth baseline, and welfare by +4.27% and +8.06%. It ranks 1 of 6 in its group on GDP at 2040, the strongest lever in the group.

Mobile money and digital payments. Mobile money moved UGX 254 trillion in the year to June 2024, up 31 per cent, across more than 43 million registered accounts — several times the assets of the banking system — and carries 61 per cent of remittance inflows [148, 326, 217]. Uganda is the only EAC country taxing withdrawals: a 0.5 per cent excise on the value withdrawn on top of 15 per cent excise on fees and withholding on agent commissions, which UNCDF and the Monitor find pushed users back toward cash after the 2018 tax [327, 77]. Treasury dropped a planned cut in 2026 [171]. The lever is the productivity of the payments system.

The benchmark for this lever is Figure 6.41.

Result. In the model this lever moves GDP by +3.84% in 2030 and +7.15% by 2040 against the balanced-growth baseline, and welfare by +3.53% and +6.43%. It ranks 2 of 6 in its group on GDP at 2040.

Broadband coverage. Coverage is no longer the constraint; use is. GSMA puts 4G population coverage at 96 per cent and the Communications Commission at 82, with 3G at 98, yet internet penetration is about 22–28 per cent and three in four people living under mobile-broadband coverage do not use it [38, 302, 84]. The Commission targets 90 per cent 4G coverage and is licensing satellite services [219]. The gap is affordability, devices and skills [161]. Kenya's penetration is roughly 40 per cent. The lever is a productivity gain in telecommunications that lowers the price of connectivity.

The benchmark for this lever is Figure 6.32.

Result. In the model this lever moves GDP by +3.45% in 2030 and +6.37% by 2040 against the balanced-growth baseline, and welfare by +3.18% and +6.01%. It ranks 3 of 6 in its group on GDP at 2040.

IT services and outsourcing. The National BPO Policy of 2025 and the BPO and IT Services Job Creation Strategy aim at 100,000 jobs by 2030 from a base of 48 registered firms and about 4,000 workers, growing around 30 per cent a year [200, 199, 209]. Uganda has been listed among the world's top 25 outsourcing destinations on cost and English [43]. Kenya's sector employs an order of magnitude more, and Rwanda has positioned itself similarly. The lever is a productivity gain in IT and business services, an intermediate input to every other sector.

Result. In the model this lever moves GDP by +3.23% in 2030 and +5.89% by 2040 against the balanced-growth baseline, and welfare by +2.96% and +5.42%. It ranks 4 of 6 in its group on GDP at 2040.

Digital government and e-services. Uganda ranked 144th on the UN E-Government Development Index in 2022 with a score of 0.44, and its online-service index fell from 58 to 52 per cent between 2020 and 2022 [138]. NITA-U runs the national backbone, the data centre, UGPass identity and the UGHub integration platform launched in 2021 to share data across ministries [210, 208]. Uganda leads the EAC on citizen-engagement and core-systems sub-indices but is held back by access, integration and awareness [93]. The lever is a productivity gain in public administration — the same services delivered with fewer resources.

Result. In the model this lever moves GDP by +2.62% in 2030 and +4.76% by 2040 against the balanced-growth baseline, and welfare by +2.40% and +4.36%. It ranks 5 of 6 in its group on GDP at 2040.

Electronic single window. The Uganda Electronic Single Window lets traders lodge customs declarations, permit applications, certificates of origin and invoices once, interfacing with ASYCUDA World, with a target of clearance within two days [325, 323]. UNCTAD's ASYCUDA programme documents similar single windows cutting clearance times by half or more elsewhere [328]. The Bureau of Standards automated import inspections in 2025 [19]. The lever models a fall in the transaction cost of trading, the same channel as trade facilitation in the services group.

The benchmark for this lever is Figure 6.36.

Result. In the model this lever moves GDP by +0.15% in 2030 and +0.28% by 2040 against the balanced-growth baseline, and welfare by +0.37% and +0.70%. It ranks 6 of 6 in its group on GDP at 2040, the weakest.

6.2.12 Water and sanitation

In this run the strongest lever in Water and sanitation is **Water supply coverage** (+5.89% GDP, +5.42% welfare at 2040), while **Sanitation spending** delivers the smallest GDP effect (-0.02%). The median lever in the group moves GDP by +3.31%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Water supply coverage	+3.23	+5.89	+2.96	+5.42
Non-revenue water reduction	+2.62	+4.76	+2.40	+4.36
Industrial water-use efficiency	+1.83	+3.31	+1.75	+3.16
Water supply spending	-0.00	-0.01	+0.00	-0.01
Sanitation spending	-0.00	-0.02	+0.00	-0.04

Table 6.12: Water and sanitation: deviation from the balanced-growth baseline.

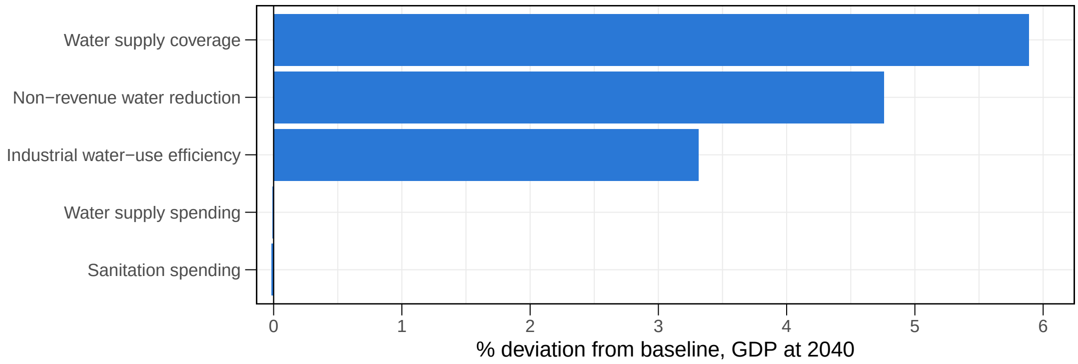

Figure 6.58: Water and sanitation: GDP deviation from baseline at 2040, by lever.

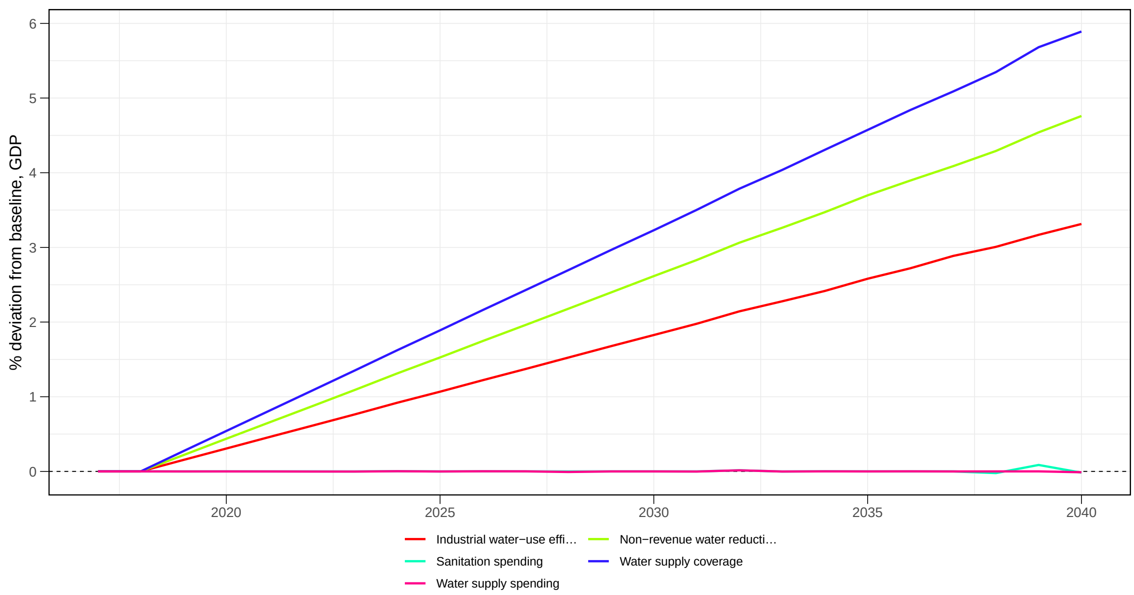

Figure 6.59: Water and sanitation: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Water supply coverage. The Ministry of Water and Environment reports 67–69 per cent rural and 72–79 per cent urban access to safe water, and that 82 per cent of villages have at least one safe source [57, 17]. The WHO/UNICEF service-ladder definitions are stricter and put safely managed water far lower [253]. The 2020 Operation and Maintenance Framework contracts rural schemes to area service providers on performance terms [146], and NWSC's 2025–2030 plan targets 26 million people served [275]. The lever is a productivity gain in water supply that extends coverage at given cost.

Result. In the model this lever moves GDP by +3.23% in 2030 and +5.89% by 2040 against the balanced-growth baseline, and welfare by +2.96% and +5.42%. It ranks 1 of 5 in its group on GDP at 2040, the strongest lever in the group.

Non-revenue water reduction. NWSC loses 34 per cent of the water it produces before it is billed, and 43.7 per cent in Kampala — leakage about 17 points, meter error 8, theft 5 [223, 65]. The five-year plan targets 28–30 per cent by 2029–30 [276, 256]. The World Bank's account of NWSC's turnaround in the 2000s shows how much of the improvement then came from the same metric [355]; Nairobi's utility partners with NWSC on it [135]. Well-run utilities operate near 15–20 per cent. The lever is a direct productivity gain in water utilities: more billed water from the same intake.

Result. In the model this lever moves GDP by +2.62% in 2030 and +4.76% by 2040 against the balanced-growth baseline, and welfare by +2.40% and +4.36%. It ranks 2 of 5 in its group on GDP at 2040.

Industrial water-use efficiency. Industry is a small abstractor in Uganda — municipal use and agriculture account for over 90 per cent of freshwater withdrawals [354, 144] — but a large polluter: effluent from the Kampala Industrial and Business Park degrades the Namanve stream into Murchison Bay, point sources around Jinja load Lake Victoria with nutrients, and eutrophication and low oxygen now affect parts of the lake [30, 348, 235]. The lever models a productivity gain in industrial water use — less water and less effluent per unit of output — which in the CGE is an input-saving technical change in manufacturing.

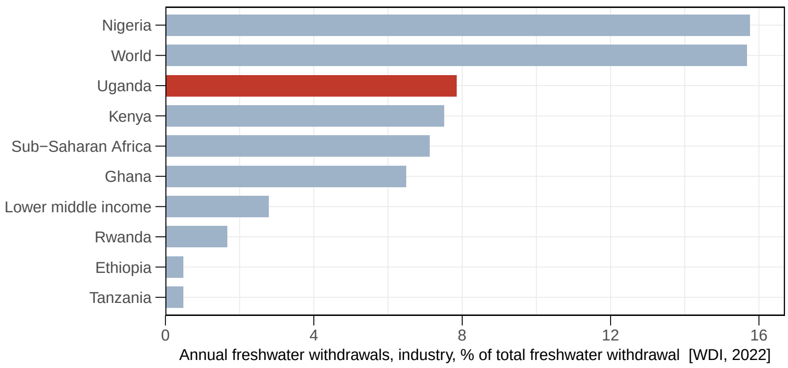

Figure 6.60: Uganda against its peers: Annual freshwater withdrawals, industry (% of total freshwater withdrawal). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +1.83% in 2030 and +3.31% by 2040 against the balanced-growth baseline, and welfare by +1.75% and +3.16%. It ranks 3 of 5 in its group on GDP at 2040.

Water supply spending. The water and environment sector has held about 3 per cent of the national budget for over five years, UGX 1.72 trillion in FY2020/21; WASH spending peaked at 0.72 per cent of GDP in 2018/19 and the 2025/26 allocation is well below that [195, 337].

Urban water's share of the WASH budget swung from 57 per cent in 2022/23 to 26 in 2024/25 and back to a projected 52, while rural water has risen slowly; external financing has been at least 58 per cent of the total in most recent years [337, 335]. The lever raises public spending on water supply within the fiscal closure.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.01% by 2040 against the balanced-growth baseline, and welfare by +0.00% and -0.01%. It ranks 4 of 5 in its group on GDP at 2040.

Sanitation spending. About a tenth of Ugandans practise open defecation, concentrated in the poorest rural fifth, and only 10–23 per cent of Kampala is connected to sewerage; the rest relies on pit latrines and faecal-sludge services [353, 382, 340]. Ministry figures of 77 per cent rural and 91 per cent urban sanitation access count any facility; the WHO/UNICEF basic-sanitation measure is about 20 per cent [57, 253]. Cost studies for Kampala show faecal-sludge treatment far cheaper per household than sewerage [340]. The lever raises public sanitation spending, whose returns in the literature run through health and labour productivity.

The benchmark for this lever is Figure 6.33.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.02% by 2040 against the balanced-growth baseline, and welfare by +0.00% and -0.04%. It ranks 5 of 5 in its group on GDP at 2040, the weakest.

6.3 Fiscal instruments

This chapter reports the 72 fiscal instruments the application carries, each solved individually to 2040. Of the 72 instruments only **27** produce a distinct answer: the remainder are tied, because instruments naming medium-30 commodities are retargeted onto the nine sectors this build carries and several then become the same shock. The ties are shown rather than hidden, since a reader is entitled to know the model was not asked the question at a resolution that could separate them.

6.3.1 Indirect tax by commodity

In this run the strongest lever in Indirect tax by commodity is **FRS — Forestry** (+0.25% GDP, -3.54% welfare at 2040), while **TRN — Transport and communications** delivers the smallest GDP effect (-0.16%). The median lever in the group moves GDP by +0.16%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Indirect taxes are the core of Uganda's revenue: VAT at 18 per cent and excise together raise more than income taxes, with taxes on goods and services other than VAT alone 32 per cent of the take in 2022 [225]. Excise is concentrated on fuel, beer and spirits, tobacco, sugar, cement and, since 2026/27, cooking fat, and the digital-stamp regime on eight products has raised collection [240, 134]. A uniform rise in the indirect tax on one commodity therefore lands very differently across the thirty: on fuel it compounds an excise already above a third of the pump price; on cereals it taxes a good that is largely exempt today.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfar
FRS — Forestry	+0.10	+0.25	-2.03	
FSH — Fishing	+0.10	+0.25	-2.03	
OXT — Other mineral extraction	+0.10	+0.25	-2.03	
MEAT — Meat products	+0.10	+0.25	-2.03	
PCF — Processed food, beverages and tobacco	+0.10	+0.25	-2.03	
TEX — Textiles, apparel and leather	+0.10	+0.25	-2.03	
WOD — Wood, paper and publishing	+0.10	+0.25	-2.03	
CHM — Chemicals, rubber, plastics, pharmaceuticals	+0.10	+0.25	-2.03	
NMM — Non-metallic minerals	+0.10	+0.25	-2.03	
MET — Metals, ferrous and non-ferrous	+0.10	+0.25	-2.03	
FMP — Fabricated metals and other manufacturing	+0.10	+0.25	-2.03	
ELE — Electronics and electrical equipment	+0.10	+0.25	-2.03	
MCH — Machinery and equipment	+0.10	+0.25	-2.03	
TEQ — Transport equipment	+0.10	+0.25	-2.03	
CNS — Construction	+0.10	+0.25	-2.03	
COAL — Coal	-0.00	+0.07	-0.00	
GRN — Cereals and grains	+0.05	+0.01	-0.68	
OSD — Oilseeds	+0.05	+0.01	-0.68	
VEG — Vegetables, fruit and other crops	+0.05	+0.01	-0.68	
ICR — Sugar crops and plant fibres	+0.05	+0.01	-0.68	
GAS — Gas and gas distribution	-0.00	+0.00	-0.00	
ELYFF — Electricity	-0.01	-0.02	-0.04	
OIL — Oil and petroleum products	-0.02	-0.04	-0.01	
CTL — Cattle, sheep and goats	-0.03	-0.06	-0.27	
OAP — Other animal products, milk, wool	-0.03	-0.06	-0.27	
WTR — Water utilities	-0.08	-0.08	-1.77	
TRD — Trade, accommodation and food services	-0.08	-0.08	-1.77	
FIN — Finance, insurance, real estate, business services	-0.08	-0.08	-1.77	
SVC — Recreation, public administration, education, health	-0.08	-0.08	-1.77	
TRN — Transport and communications	-0.10	-0.16	-1.88	

Table 6.13: Indirect tax by commodity: deviation from the balanced-growth baseline.

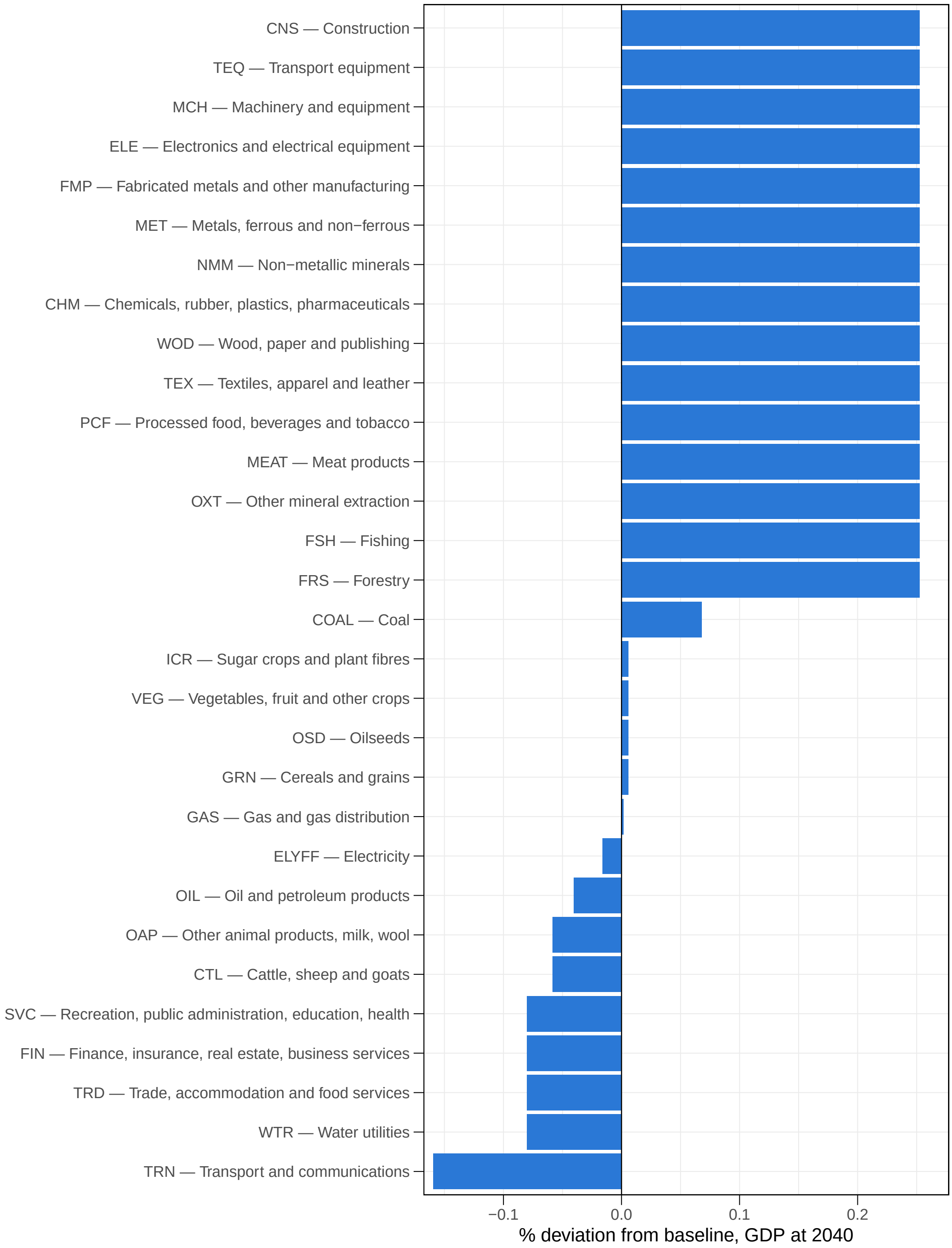

Figure 6.61: Indirect tax by commodity: GDP deviation from baseline at 2040, by lever.

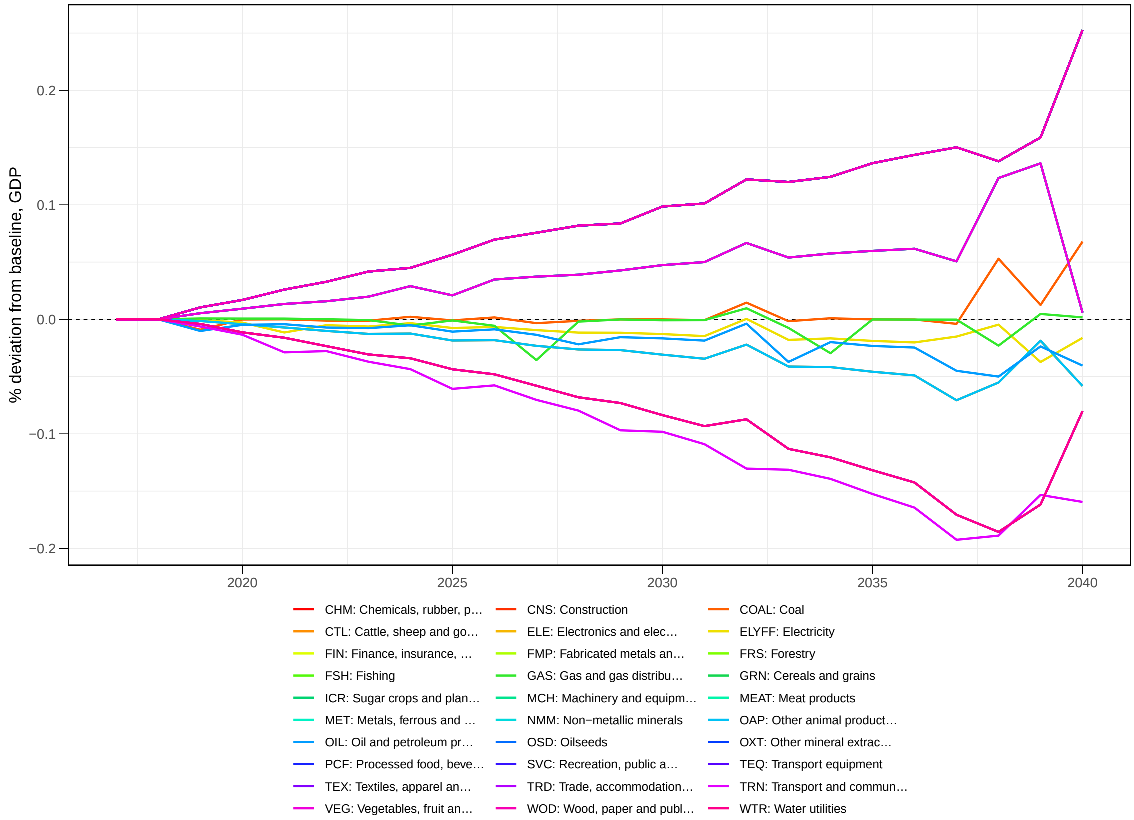

Figure 6.62: Indirect tax by commodity: GDP deviation paths to 2040.

6.3.2 Production tax by activity

In this run the strongest lever in Production tax by activity is **FRS — Forestry** (+0.25% GDP, -3.55% welfare at 2040), while **TRN — Transport and communications** delivers the smallest GDP effect (-0.15%). The median lever in the group moves GDP by +0.17%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

A production tax falls on the activity rather than on the commodity, so it is closer to corporate income tax, licence fees, royalties and sector levies than to VAT. In Uganda those are the 30 per cent corporate rate with its many incentives [155], the mining royalties reset by the 2022 Act [2], the levies on telecoms and financial services, and the production-side excises on beer and sugar. The thirty levers here raise the tax on each activity's output by the same proportion; which of them costs GDP most depends on how large the activity is and how easily its factors move.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfar
FRS — Forestry	+0.10	+0.25	-2.03	
FSH — Fishing	+0.10	+0.25	-2.03	
OXT — Other mineral extraction	+0.10	+0.25	-2.03	
MEAT — Meat products	+0.10	+0.25	-2.03	
PCF — Processed food, beverages and tobacco	+0.10	+0.25	-2.03	
TEX — Textiles, apparel and leather	+0.10	+0.25	-2.03	
WOD — Wood, paper and publishing	+0.10	+0.25	-2.03	
CHM — Chemicals, rubber, plastics, pharmaceuticals	+0.10	+0.25	-2.03	
NMM — Non-metallic minerals	+0.10	+0.25	-2.03	
MET — Metals, ferrous and non-ferrous	+0.10	+0.25	-2.03	
FMP — Fabricated metals and other manufacturing	+0.10	+0.25	-2.03	
ELE — Electronics and electrical equipment	+0.10	+0.25	-2.03	
MCH — Machinery and equipment	+0.10	+0.25	-2.03	
TEQ — Transport equipment	+0.10	+0.25	-2.03	
CNS — Construction	+0.10	+0.25	-2.03	
GRN — Cereals and grains	+0.05	+0.10	-0.68	
OSD — Oilseeds	+0.05	+0.10	-0.68	
VEG — Vegetables, fruit and other crops	+0.05	+0.10	-0.68	
ICR — Sugar crops and plant fibres	+0.05	+0.10	-0.68	
OIL — Oil and petroleum products	-0.02	+0.05	-0.01	
COAL — Coal	-0.00	+0.00	-0.00	
GAS — Gas and gas distribution	-0.00	+0.00	-0.00	
ELYFF — Electricity	-0.01	-0.02	-0.04	
CTL — Cattle, sheep and goats	-0.03	-0.07	-0.27	
OAP — Other animal products, milk, wool	-0.03	-0.07	-0.27	
WTR — Water utilities	-0.08	-0.11	-1.77	
TRD — Trade, accommodation and food services	-0.08	-0.11	-1.77	
FIN — Finance, insurance, real estate, business services	-0.08	-0.11	-1.77	
SVC — Recreation, public administration, education, health	-0.08	-0.11	-1.77	
TRN — Transport and communications	-0.10	-0.15	-1.88	

Table 6.14: Production tax by activity: deviation from the balanced-growth baseline.

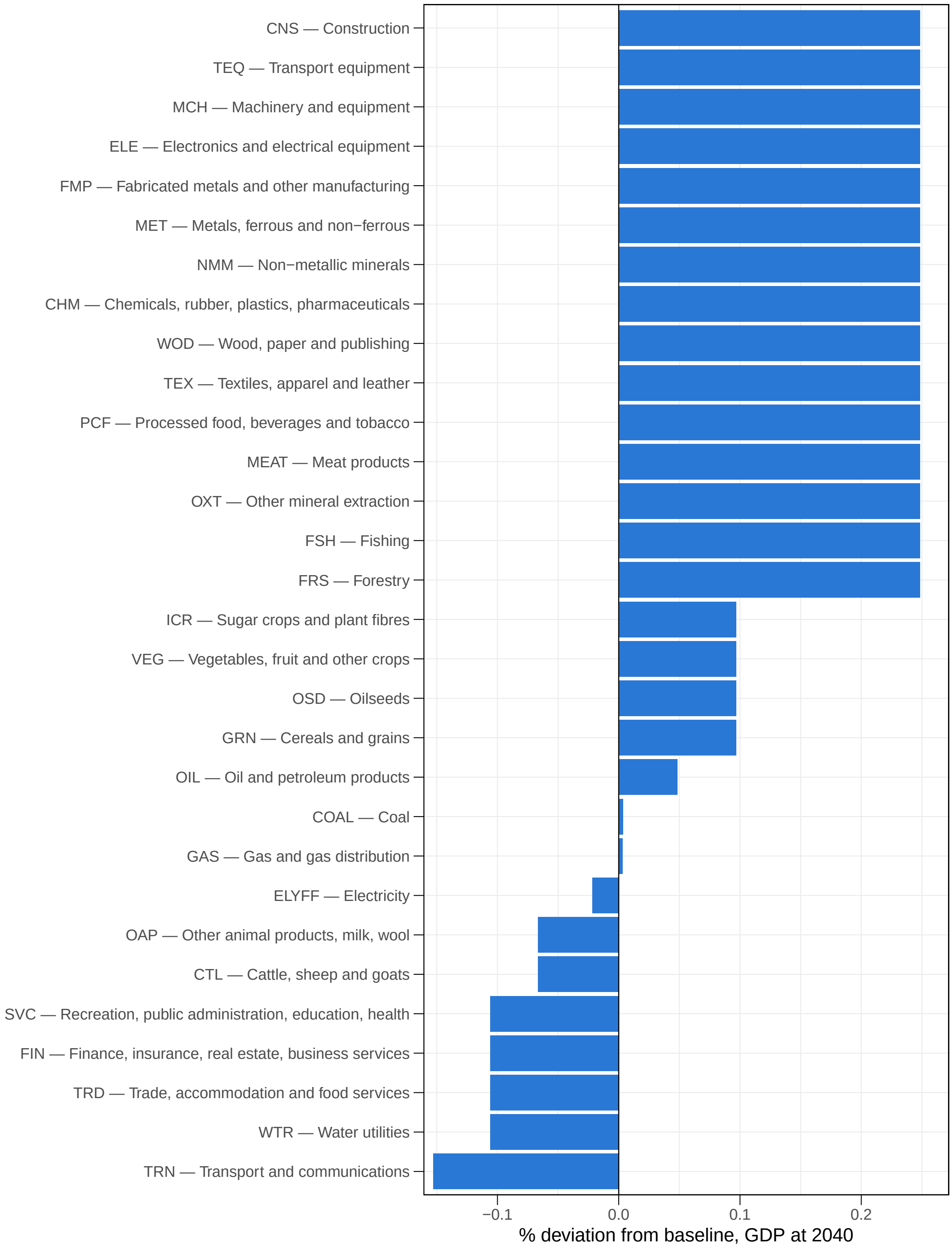

Figure 6.63: Production tax by activity: GDP deviation from baseline at 2040, by lever.

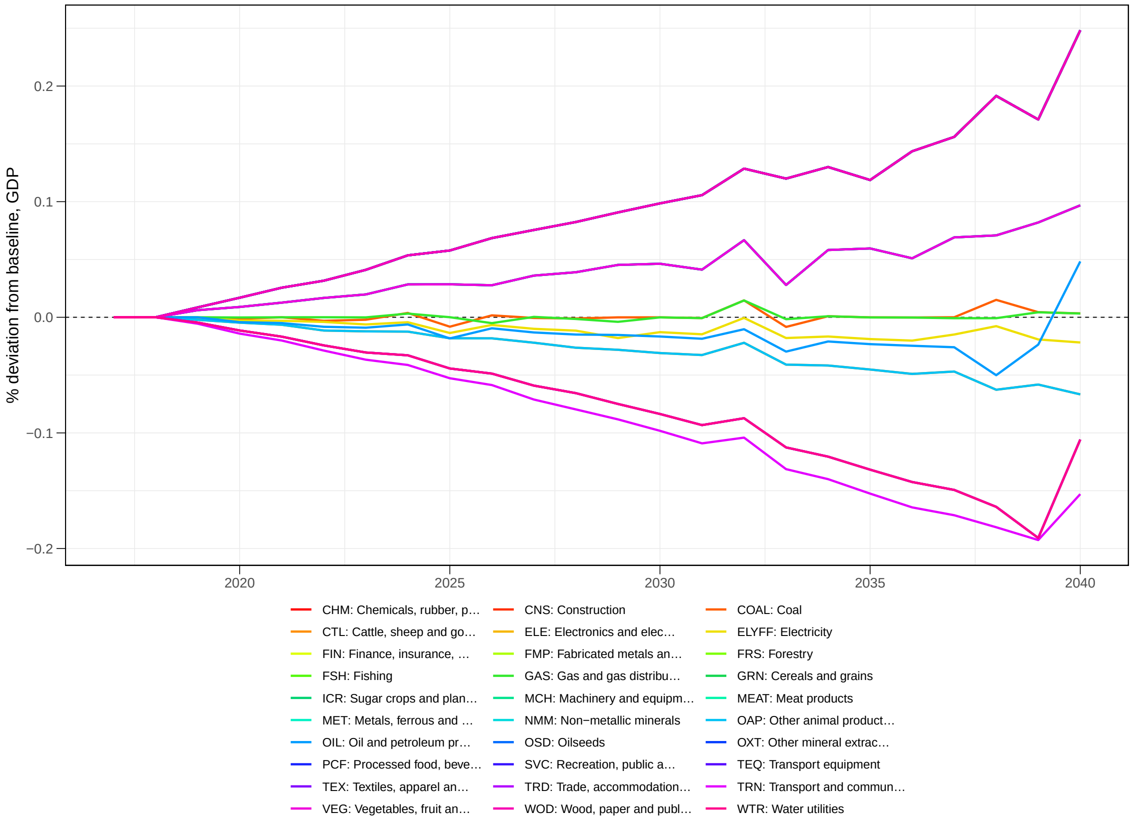

Figure 6.64: Production tax by activity: GDP deviation paths to 2040.

6.3.3 Other revenue instruments

In this run the strongest lever in Other revenue instruments is **Direct tax on income** (+0.03% GDP, -5.07% welfare at 2040), while **Import tariff — all imports** delivers the smallest GDP effect (-0.21%). The median lever in the group moves GDP by -0.10%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Direct tax on income	+0.03	+0.03	-2.73	-5.07
Carbon price	-0.09	-0.10	-0.21	-0.18
Import tariff — all imports	-0.17	-0.21	-0.50	-0.66

Table 6.15: Other revenue instruments: deviation from the balanced-growth baseline.

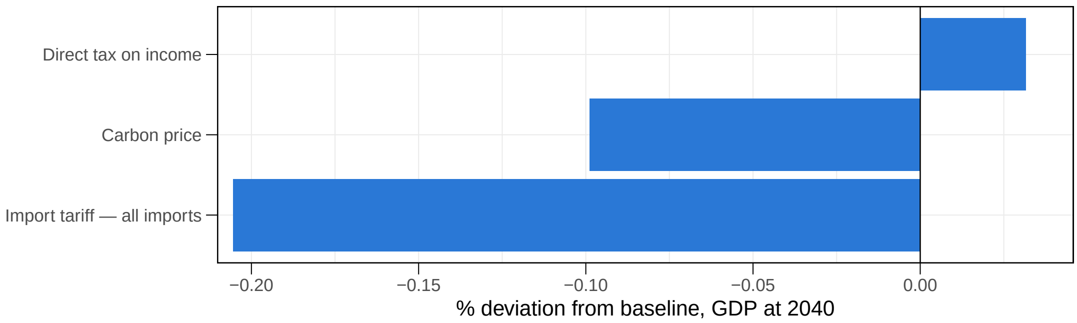

Figure 6.65: Other revenue instruments: GDP deviation from baseline at 2040, by lever.

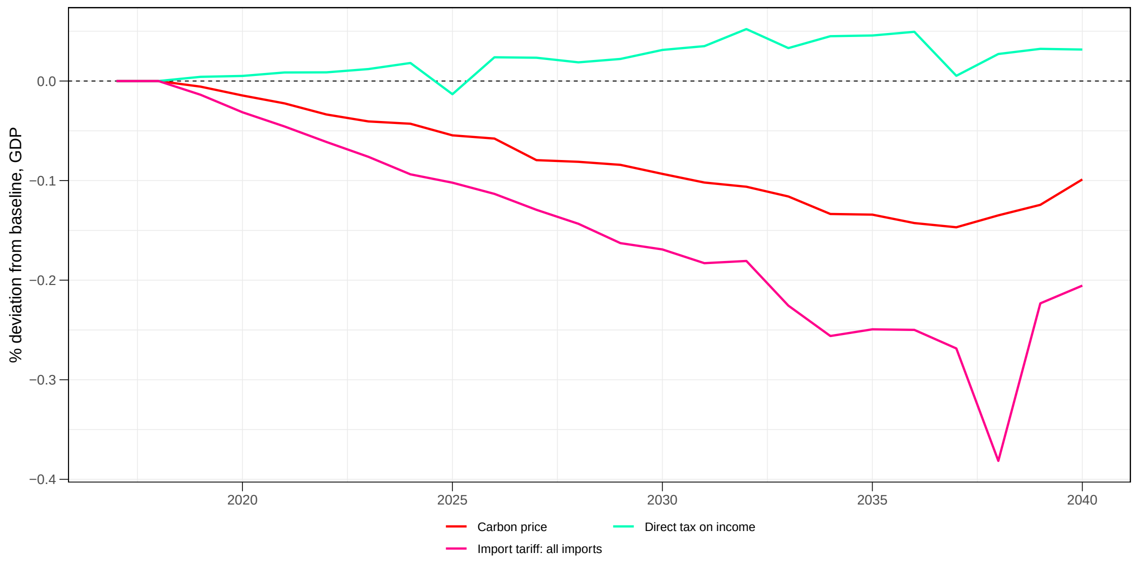

Figure 6.66: Other revenue instruments: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Direct tax on income. Uganda's tax take is 12.5–14 per cent of GDP, below the African average of 16 and well below Kenya's; the Domestic Revenue Mobilisation Strategy targets 18 per cent in the medium term [225, 71, 174]. Taxes on income and profits are about a third of revenue, PAYE on formal wages the largest single line, with a top marginal rate of 40 per cent on a base of about 2.2 million formal jobs [225, 155]. The International Growth Centre finds tax incentives and exemptions erode the base more than rates constrain it [155]. The lever raises the direct-tax rate on household income, which in the model finances a fall in the deficit or in other taxes.

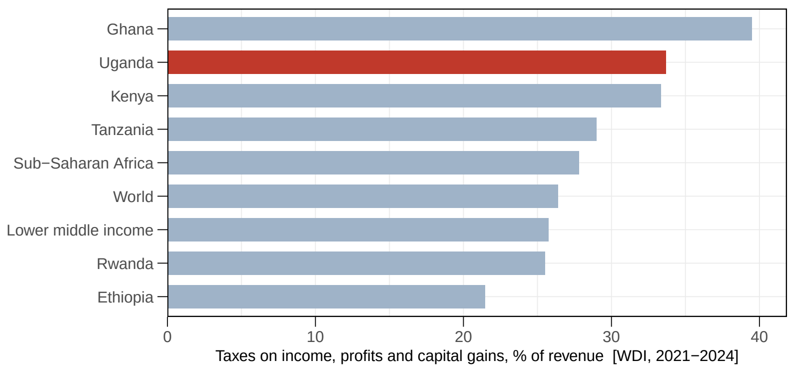

Figure 6.67: Uganda against its peers: Taxes on income, profits and capital gains (% of revenue). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.03% in 2030 and +0.03% by 2040 against the balanced-growth baseline, and welfare by -2.73% and -5.07%. It ranks 1 of 3 in its group on

GDP at 2040, the strongest lever in the group. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

Carbon price. Uganda has no carbon tax. The National Climate Change Act 2021 and the Climate Change Mechanisms Regulations of 2025 set up a carbon-market framework — registration of projects, verifiers, benefit-sharing and Article 6 transfers — rather than a price on domestic emissions [329, 10]. The Ministry of Finance's own policy brief on climate finance argues for an explicit carbon tax as the simplest instrument, with revenue earmarked to climate action [196]. Uganda's energy-related emissions are small and mostly transport fuel; the excise on petrol and diesel, raised by UGX 200 a litre in 2026/27, already functions as an implicit carbon price [240]. The lever applies an explicit price to fuel combustion.

Result. In the model this lever moves GDP by -0.09% in 2030 and -0.10% by 2040 against the balanced-growth baseline, and welfare by -0.21% and -0.18%. It ranks 2 of 3 in its group on GDP at 2040.

Import tariff — all imports. Uganda's tariff schedule is the EAC Common External Tariff of 0, 10, 25 and, since 2022, 35 per cent, so a uniform change in the tariff is a change in the whole EAC schedule as applied at Uganda's border [95, 320]. The trade-weighted average applied rate is about 8 per cent [379]. Trade taxes remain a large share of revenue — the OECD puts customs and excise on imports together above a third of the take — which is why Uganda has been slower than its neighbours to lower them [225]. The lever raises the tariff on all imports by the same proportion.

The benchmark for this lever is Figure 6.22.

Result. In the model this lever moves GDP by -0.17% in 2030 and -0.21% by 2040 against the balanced-growth baseline, and welfare by -0.50% and -0.66%. It ranks 3 of 3 in its group on GDP at 2040, the weakest.

6.3.4 Government spending by function

In this run the strongest lever in Government spending by function is **Energy** (+0.00% GDP, +0.02% welfare at 2040), while **Health** delivers the smallest GDP effect (-0.03%). The median lever in the group moves GDP by -0.00%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Energy	+0.00	+0.00	+0.01	+0.02
Rail	-0.00	-0.00	+0.00	+0.01
Water transport and ports	-0.00	-0.00	+0.00	+0.01
Sanitation	-0.00	-0.00	+0.00	+0.01
Roads	+0.00	-0.00	+0.02	+0.02
Education	-0.00	-0.01	+0.04	+0.06
Water supply	-0.00	-0.01	+0.00	-0.01
Public administration and defence	-0.01	-0.01	+0.10	+0.18
Health	+0.00	-0.03	+0.02	-0.04

Table 6.16: Government spending by function: deviation from the balanced-growth baseline.

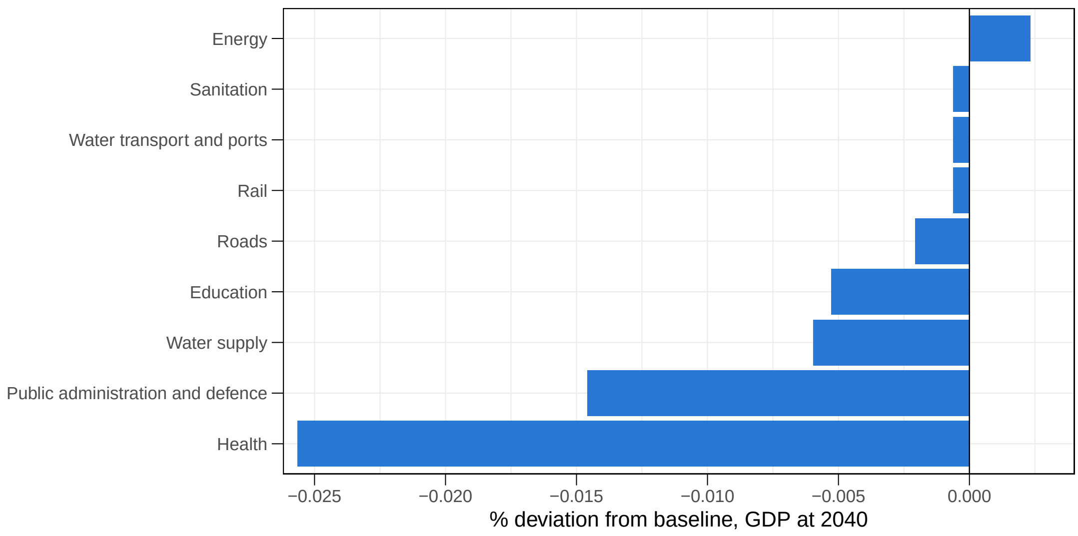

Figure 6.68: Government spending by function: GDP deviation from baseline at 2040, by lever.

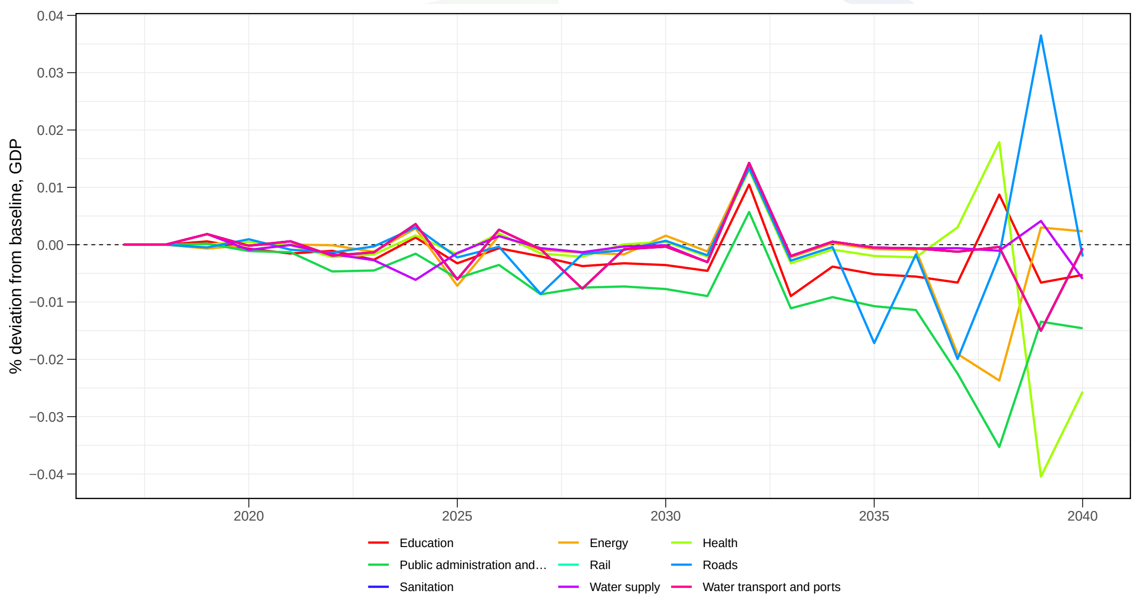

Figure 6.69: Government spending by function: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Energy. The energy vote is UGX 2.07 trillion in FY2026/27, for Kiba hydropower, floating and utility-scale solar, transmission, rural electrification and industrial connections, on top of about UGX 800 billion a year in tariff support [296, 295]. With generation in surplus, the marginal shilling goes to wires and connections [109]. The lever raises public energy spending as government investment.

Result. In the model this lever moves GDP by +0.00% in 2030 and +0.00% by 2040 against the balanced-growth baseline, and welfare by +0.01% and +0.02%. It ranks 1 of 9 in its group on GDP at 2040, the strongest lever in the group.

Rail. Rail spending is the EUR 2.7 billion Malaba–Kampala standard-gauge contract with Yapı Merkezi, the AfDB-financed refurbishment of the metre-gauge Malaba–Kampala line and the Tororo–Gulu restoration [242, 7]. Only 265 of 1,266 km of the old network operate [317]. The lever raises public rail spending as government investment.

The benchmark for this lever is Figure 6.37.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.00% by 2040 against the balanced-growth baseline, and welfare by +0.00% and +0.01%. It ranks 2 of 9 in its group on GDP at 2040. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

Water transport and ports. Lake Victoria carries a fraction of the cargo it could. Port Bell has a 2,000-tonne dry dock but no cargo-handling equipment and a shortage of shunting locomotives; the MV Uhuru wagon ferry stopped in 2006 and Kenya's refurbished vessel now carries fuel to Uganda; the UGX 800 billion Bukasa port, planned for 5.2 million tonnes a year, is stalled on land and tendering [265, 56, 186]. The EastAfrican puts the lake's untapped trade potential at US$60 billion [265]. The lever raises public spending on water transport and ports as government investment.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.00% by 2040 against the balanced-growth baseline, and welfare by +0.00% and +0.01%. It ranks 3 of 9 in its group on GDP at 2040. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

Sanitation. Sanitation is the smaller half of the WASH budget. About a tenth of the population practises open defecation and Kampala's sewer network reaches 10–23 per cent of the city, so public sanitation spending in Uganda is mostly faecal-sludge management and latrine promotion rather than sewerage [353, 382]. The lever raises public sanitation spending as government investment.

The benchmark for this lever is Figure 6.33.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.00% by 2040 against the balanced-growth baseline, and welfare by +0.00% and +0.01%. It ranks 4 of 9 in its group on GDP at 2040. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

Roads. Roads have been the largest infrastructure vote for two decades, and the network shows it: national roads are a quarter paved and largely in fair-to-good condition, while the district and community roads that carry farm produce are mostly earth and a third in acceptable condition [204, 70]. The Ministry of Works absorbed UNRA in 2024. Maintenance rather than construction is the weakness the research identifies [311]. The lever raises public road spending as government investment.

Result. In the model this lever moves GDP by +0.00% in 2030 and -0.00% by 2040 against the balanced-growth baseline, and welfare by +0.02% and +0.02%. It ranks 5 of 9 in its group on GDP at 2040. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

Education. Public education spending is 2.5–2.7 per cent of GDP against 3.3 in Tanzania, 3.8 in Rwanda and 4.8 in Kenya, and about 10–11 per cent of the budget against Kenya's 23 [66, 336]. The human-capital sector as a whole, education and health together, is the largest budget line at UGX 9.9 trillion in FY2025/26 [228]. This fiscal lever raises the education vote as government consumption, and differs from the sector levers in the education group, which model the productivity effects of the same spending.

The benchmark for this lever is Figure 6.54.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.01% by 2040 against the balanced-growth baseline, and welfare by +0.04% and +0.06%. It ranks 6 of 9 in its group on GDP at 2040. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

Water supply. The water and environment sector has held about 3 per cent of the budget for five years; WASH spending peaked at 0.72 per cent of GDP in 2018/19 and has not returned to it, with external financing at least 58 per cent of the total in most recent years [337, 195]. Coverage is 67–69 per cent rural and 72–79 urban on the ministry's definitions [57]. The lever raises public water-supply spending as government investment.

Result. In the model this lever moves GDP by -0.00% in 2030 and -0.01% by 2040 against the balanced-growth baseline, and welfare by +0.00% and -0.01%. It ranks 7 of 9 in its group on GDP at 2040.

Public administration and defence. Governance and security is the second-largest budget sector after human capital, UGX 8.3 trillion in FY2025/26, of which defence takes UGX 3.7 trillion — UGX 1.7 trillion recurrent and UGX 2.0 trillion for equipment [228]. Salary enhancements pushed the public wage bill to UGX 9.7 trillion in the FY2026/27 budget [216]. Government consumption is about 8 per cent of GDP. The lever raises spending on administration and defence, pure government consumption in the model with no productivity channel, so its result is the fiscal crowding-out effect alone.

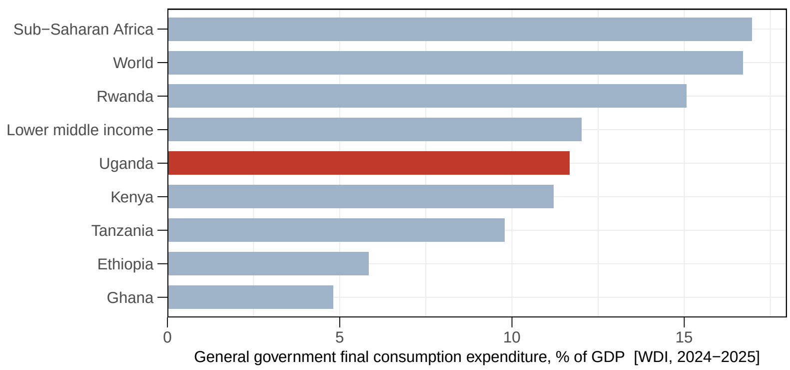

Figure 6.70: Uganda against its peers: General government final consumption expenditure (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by -0.01% in 2030 and -0.01% by 2040 against the balanced-growth baseline, and welfare by +0.10% and +0.18%. It ranks 8 of 9 in its group on GDP at 2040. GDP and welfare move in opposite directions, so the lever shifts resources rather than creating them.

Health. Government health spending runs at 6–10 per cent of the budget against the 15 per cent Abuja pledge and about US$23 per person [338, 83]. Its exposure to aid is the fact of 2025: donors funded the larger part of health spending, and the ministry projects a 49 per cent fall in external health financing after the US and other cuts, with donor loans and grants overall down 84 per cent in two years [87, 72]. The lever raises the health vote as government consumption; the health-sector levers model what the spending buys.

The benchmark for this lever is Figure 6.48.

Result. In the model this lever moves GDP by +0.00% in 2030 and -0.03% by 2040 against the balanced-growth baseline, and welfare by +0.02% and -0.04%. It ranks 9 of 9 in its group on GDP at 2040, the weakest.

6.4 The external sector

This chapter reports the 63 the external sector the application carries, each solved individually to 2040. Of the 63 instruments only **20** produce a distinct answer: the remainder are tied, because instruments naming medium-30 commodities are retargeted onto the nine sectors this build carries and several then become the same shock. The ties are shown rather than hidden, since a reader is entitled to know the model was not asked the question at a resolution that could separate them.

6.4.1 World import prices by commodity

In this run the strongest lever in World import prices by commodity is **FRS — Forestry** (+0.24% GDP, +0.34% welfare at 2040), while **OIL — Oil and petroleum products** delivers the smallest GDP effect (-0.09%). The median lever in the group moves GDP by +0.15%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Uganda's imports are about US$10–11 billion a year: petroleum products (US$2 billion, 2.5 billion litres, 90 per cent through Kenya), machinery and electrical equipment, vehicles, iron and steel (US$527 million), pharmaceuticals (80 per cent imported, 60 per cent from India), palm oil and gold for refining [299, 312, 166, 290]. Tanzania overtook China and Kenya as the largest source in 2025, with China at 19 per cent [79]. A rise in the world price of an import therefore hurts in proportion to that bill and helps only where Uganda also produces the good.

The thirty instruments in this block carry nine distinct answers, so they are reported as charts rather than as a thirty-row table; see Section 6.4.5, where the two world-price blocks are compared directly.

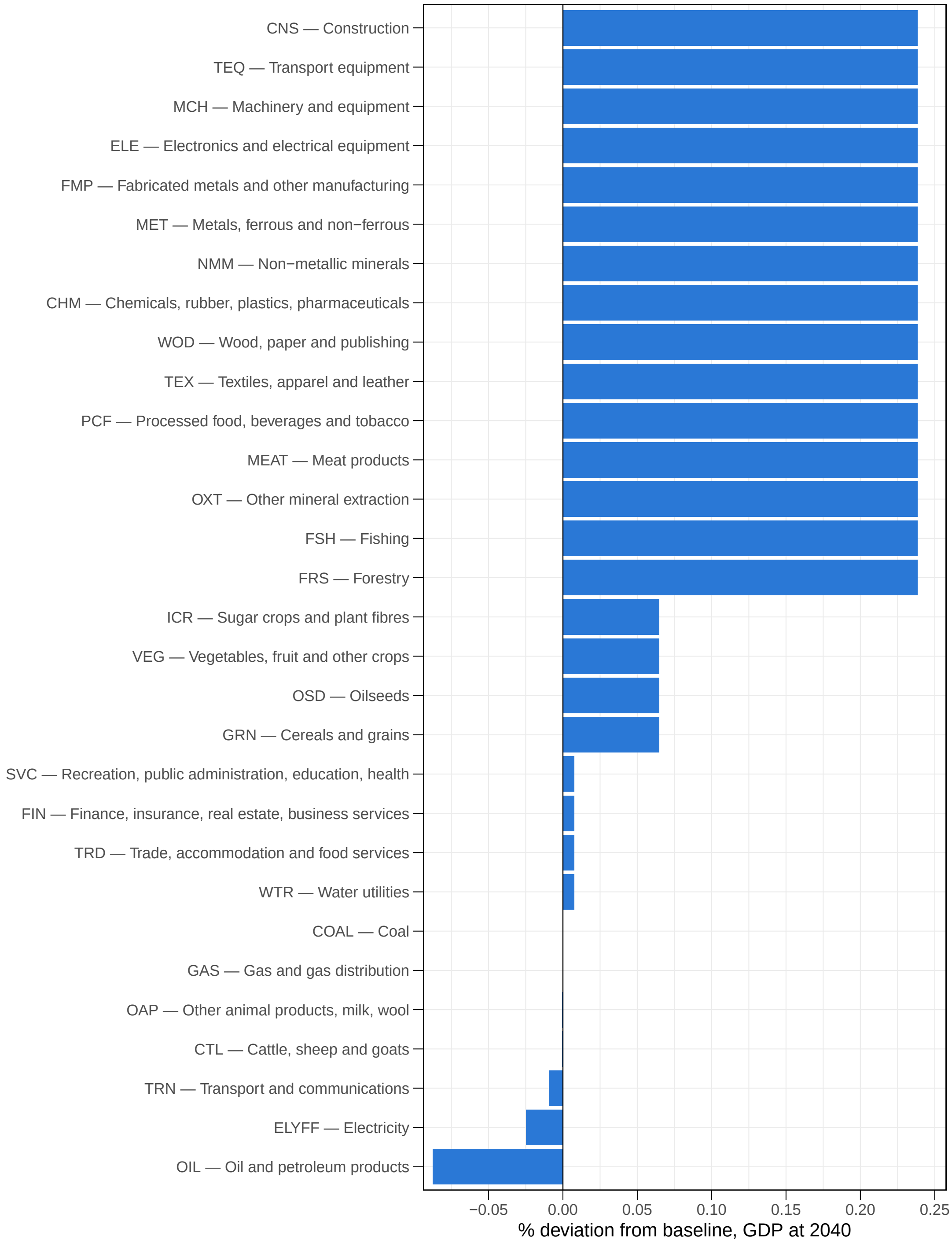

Figure 6.71: World import prices by commodity: GDP deviation from baseline at 2040, by lever.

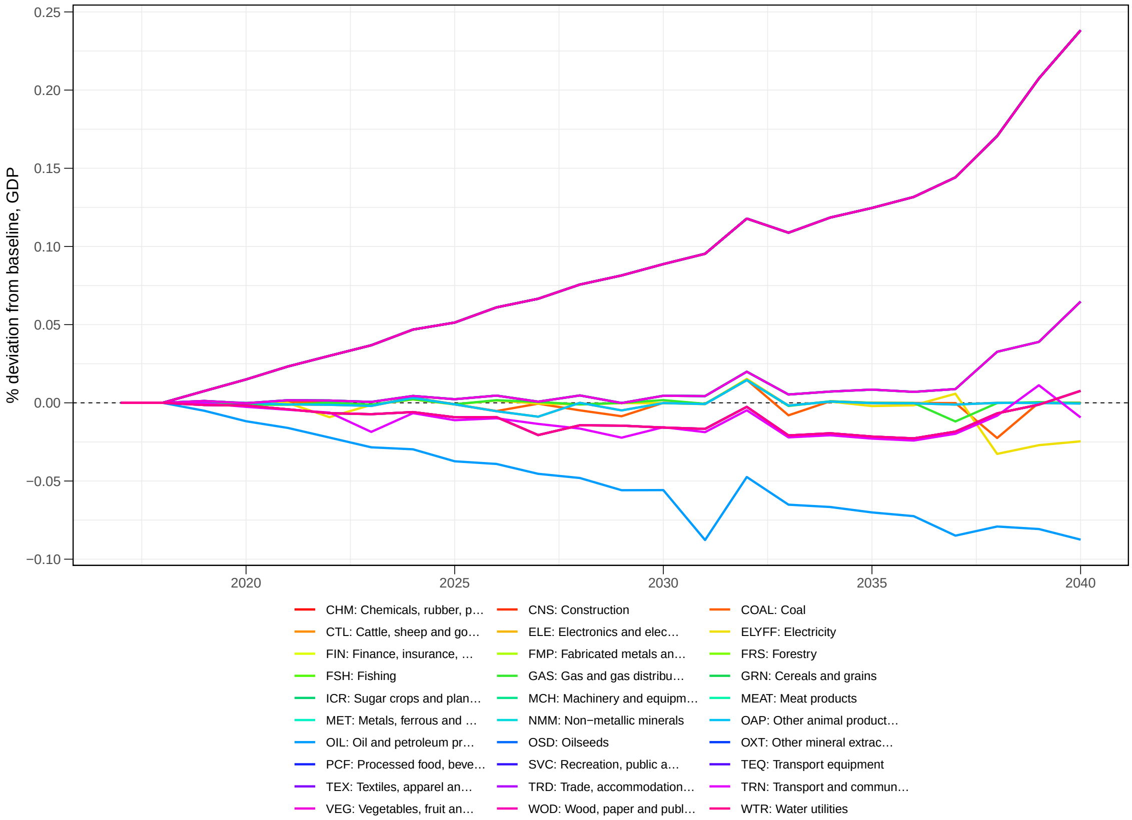

Figure 6.72: World import prices by commodity: GDP deviation paths to 2040.

6.4.2 World export prices by commodity

In this run the strongest lever in World export prices by commodity is **FRS — Forestry** (+0.41% GDP, +0.97% welfare at 2040), while **COAL — Coal** delivers the smallest GDP effect (-0.16%). The median lever in the group moves GDP by +0.39%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Uganda's exports reached a record UGX 43–46 trillion (about US$10.6 billion) in 2024–25: gold 39–40 per cent, most of it refined from regional supply; coffee 19 per cent at US$2.2 billion; then cocoa, fish, dairy, maize, sugar, cement and manufactured goods to the EAC, DRC and South Sudan [81, 18, 97]. Bussolo and colleagues' study of the 1990s coffee boom found the price gains reached poor and rich growers alike and spilled into non-coffee activity in coffee districts [12]. A world export-price rise is a terms-of-trade gain in proportion to the export share; the 2024/25 coffee price doubling is the live example.

The thirty instruments in this block carry nine distinct answers, so they are reported as charts rather than as a thirty-row table; see Section 6.4.5, where the two world-price blocks are compared directly.

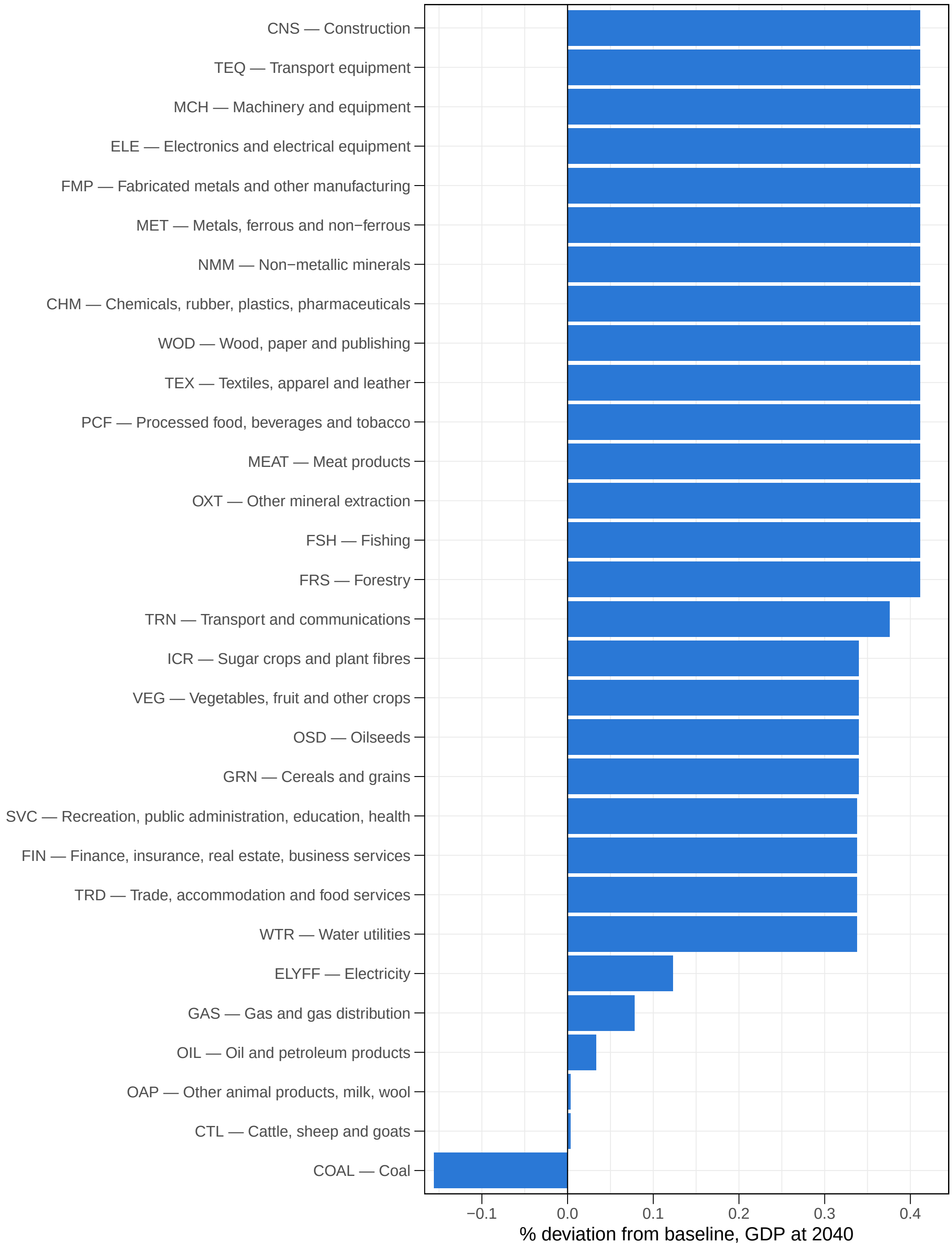

Figure 6.73: World export prices by commodity: GDP deviation from baseline at 2040, by lever.

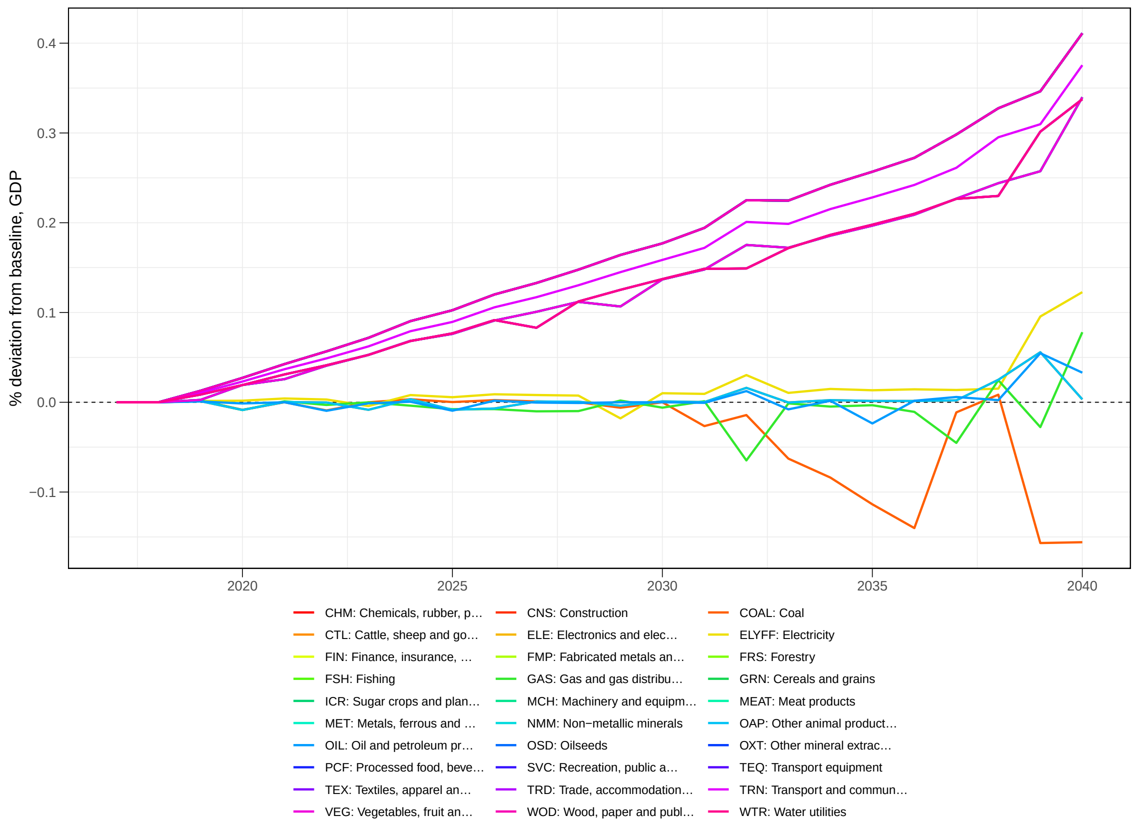

Figure 6.74: World export prices by commodity: GDP deviation paths to 2040.

6.4.3 Transfers and capital flows

In this run the strongest lever in Transfers and capital flows is **Foreign direct investment and net foreign saving** (+1.03% GDP, +2.18% welfare at 2040), while **Remittances and current transfers** delivers the smallest GDP effect (+0.32%). The median lever in the group moves GDP by +1.03%. The full ranking is reported in the table, with the 2040 outcomes charted below it and the year-by-year deviation paths thereafter.

Lever	%GDP 2030	%GDP 2040	%Welfare 2030	%Welfare 2040
Foreign direct investment and net foreign saving	+1.04	+1.03	+2.17	+2.18
Official development assistance to government	+1.04	+1.03	+2.17	+2.18
Remittances and current transfers	+0.31	+0.32	+3.13	+3.43

Table 6.17: Transfers and capital flows: deviation from the balanced-growth baseline.

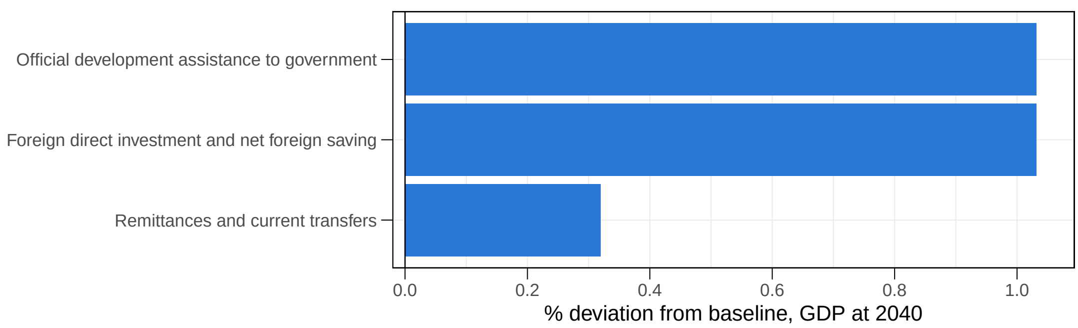

Figure 6.75: Transfers and capital flows: GDP deviation from baseline at 2040, by lever.

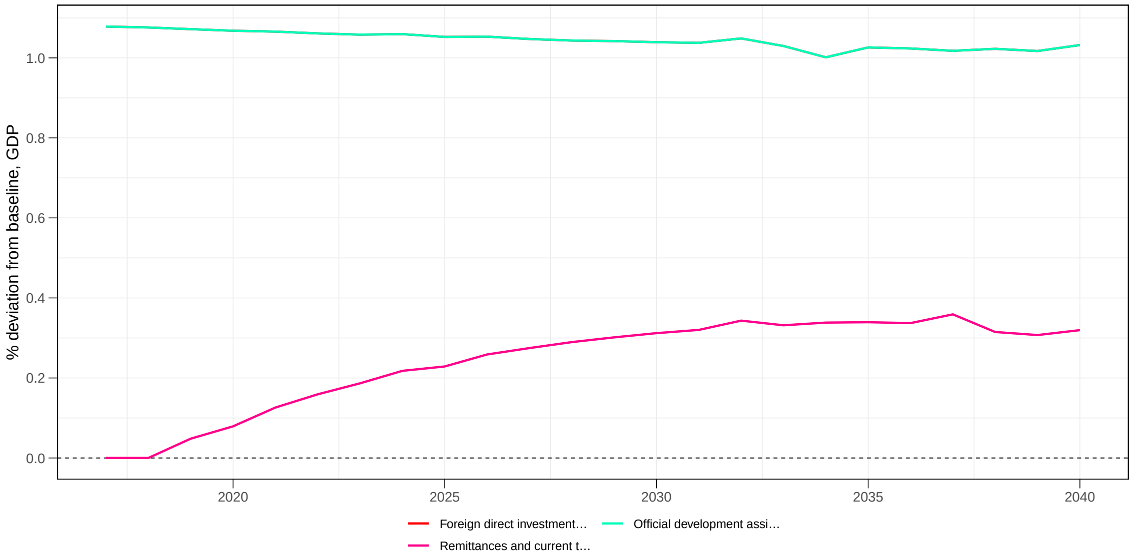

Figure 6.76: Transfers and capital flows: GDP deviation paths to 2040.

The levers in detail

Each lever is set in its Ugandan context from the published record — what the country does today, how that compares with its neighbours — and then read against the model's answer. The benchmark charts draw the latest World Development Indicators value for Uganda, Kenya, Tanzania, Rwanda, Ethiopia, Ghana, Nigeria and the Sub-Saharan, low-income and world aggregates.

Foreign direct investment and net foreign saving. FDI inflows were US$2.9–3.3 billion in 2023–24, among the highest in East Africa relative to GDP, and almost entirely oil: mining and quarrying plus pipeline transport were 79 per cent of inflows in 2024 and 97 per cent in 2023 [27, 80, 179]. The FDI stock is about US$19.5 billion, 38 per cent of GDP [179]. The US State Department's investment-climate statement lists land, contract enforcement and policy predictability as the constraints outside oil [292]. The lever raises net foreign saving by 3 per cent of GDP, which in the model finances investment and appreciates the real exchange rate.

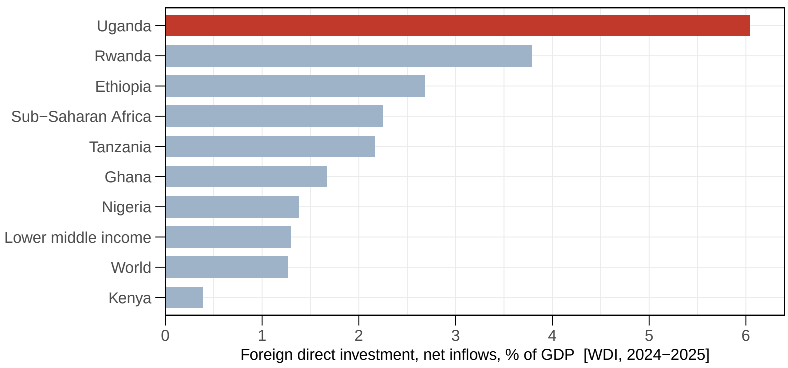

Figure 6.77: Uganda against its peers: Foreign direct investment, net inflows (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +1.04% in 2030 and +1.03% by 2040 against the balanced-growth baseline, and welfare by +2.17% and +2.18%. It ranks 1 of 3 in its group on GDP at 2040, the strongest lever in the group.

Official development assistance to government. Aid to Uganda's budget has collapsed. Donor loans and grants fell from US$905 million in June 2023 to US$146 million, an 84 per cent decline in two years, and the budget's donor line from UGX 2.8 trillion to UGX 29 billion [72, 87]. The 2025 US cuts of about US$950 million landed hardest on health, where donors had funded the larger share [87, 16]. UNU-WIDER's work on aid and fiscal behaviour in Uganda finds aid historically raised spending more than it displaced revenue effort [339]. The lever raises ODA to government; the same channel run backwards is the 2025 experience.

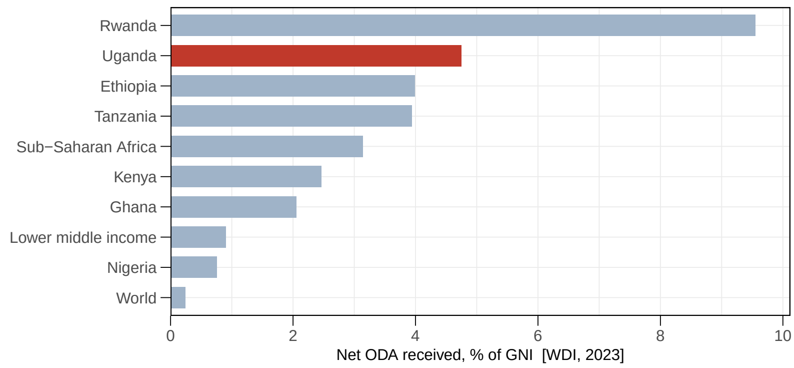

Figure 6.78: Uganda against its peers: Net ODA received (% of GNI). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +1.04% in 2030 and +1.03% by 2040 against the balanced-growth baseline, and welfare by +2.17% and +2.18%. It ranks 2 of 3 in its group on GDP at 2040.

Remittances and current transfers. Remittances reached US$1.42 billion in the year to January 2024 and US$2.5 billion in 2025, about 3.8 per cent of GDP, from the United States, the Gulf and South Africa; 73 per cent arrive digitally and 61 per cent by mobile money [78, 218, 142]. Kenya's inflows are about 3 per cent of GDP and much larger in dollars. The Economic Policy Research Centre argues the flows now rival coffee and FDI as a source of foreign exchange [104]. The lever raises remittances by 3 per cent of GDP; in the model they enter household income directly.

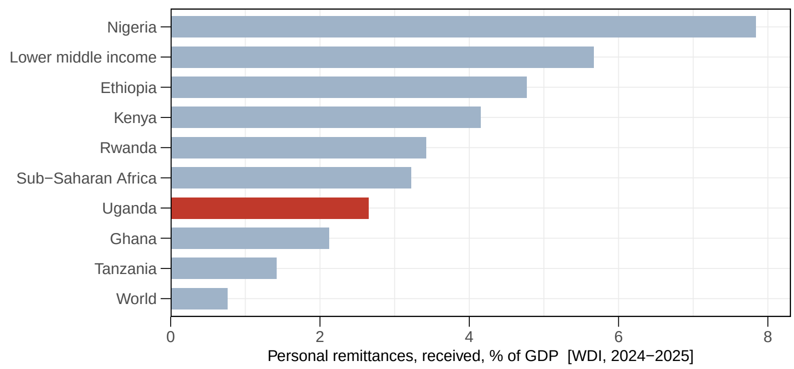

Figure 6.79: Uganda against its peers: Personal remittances, received (% of GDP). Latest value in the World Development Indicators [362].

Result. In the model this lever moves GDP by +0.31% in 2030 and +0.32% by 2040 against the balanced-growth baseline, and welfare by +3.13% and +3.43%. It ranks 3 of 3 in its group on GDP at 2040, the weakest.

6.4.4 Export and import growth under the external levers

The external levers act on Uganda's trade first and on GDP second, so this section reports what they do to the growth of real exports and imports. For each block the first chart gives the average annual growth rate of exports and imports over 2026–2040 under every lever as the difference from the baseline rate; the second gives the year-by-year deviation of the export and import *levels* from the baseline path.

6.4.4.1 World import prices by commodity

In the baseline real exports grow +5.01% a year and imports +5.03% a year over 2026–2040. Within this block the fastest export growth comes under **WOD — Wood, paper and publishing** (+5.64% a year) and the slowest under **ELYFF — Electricity** (+4.97%); import growth is highest under **CHM — Chemicals, rubber, plastics, pharmaceuticals** (+5.37%) and lowest under **ELYFF — Electricity** (+5.01%). A lever that raises export growth and lowers import growth is improving the trade balance; one that raises both is expanding trade at a roughly constant balance, which is the usual signature of a terms-of-trade or transfer gain spent partly on imports.

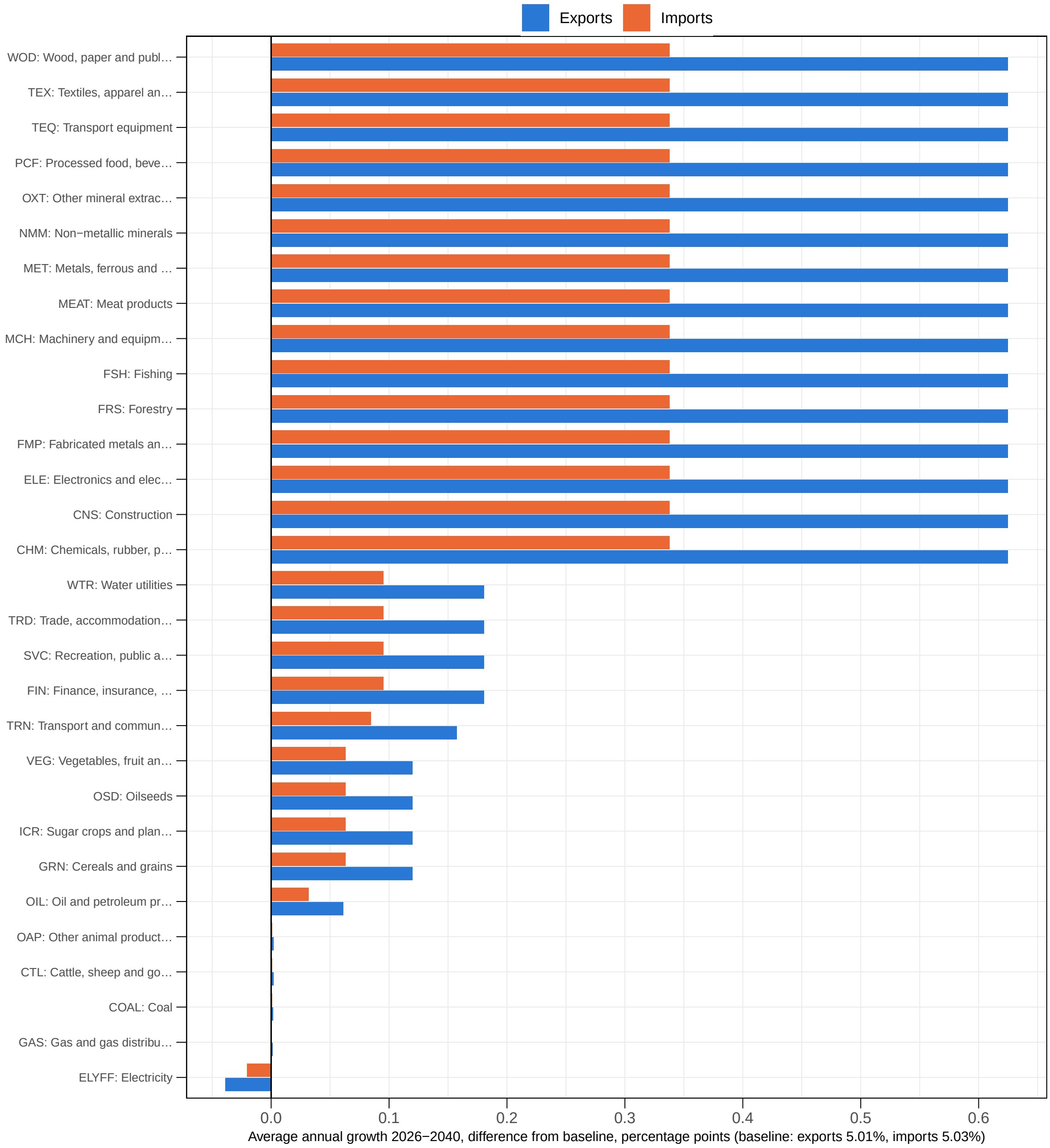

Figure 6.80: World import prices by commodity: average annual growth of real exports and imports over 2026–2040, difference from the baseline rate in percentage points, by lever.

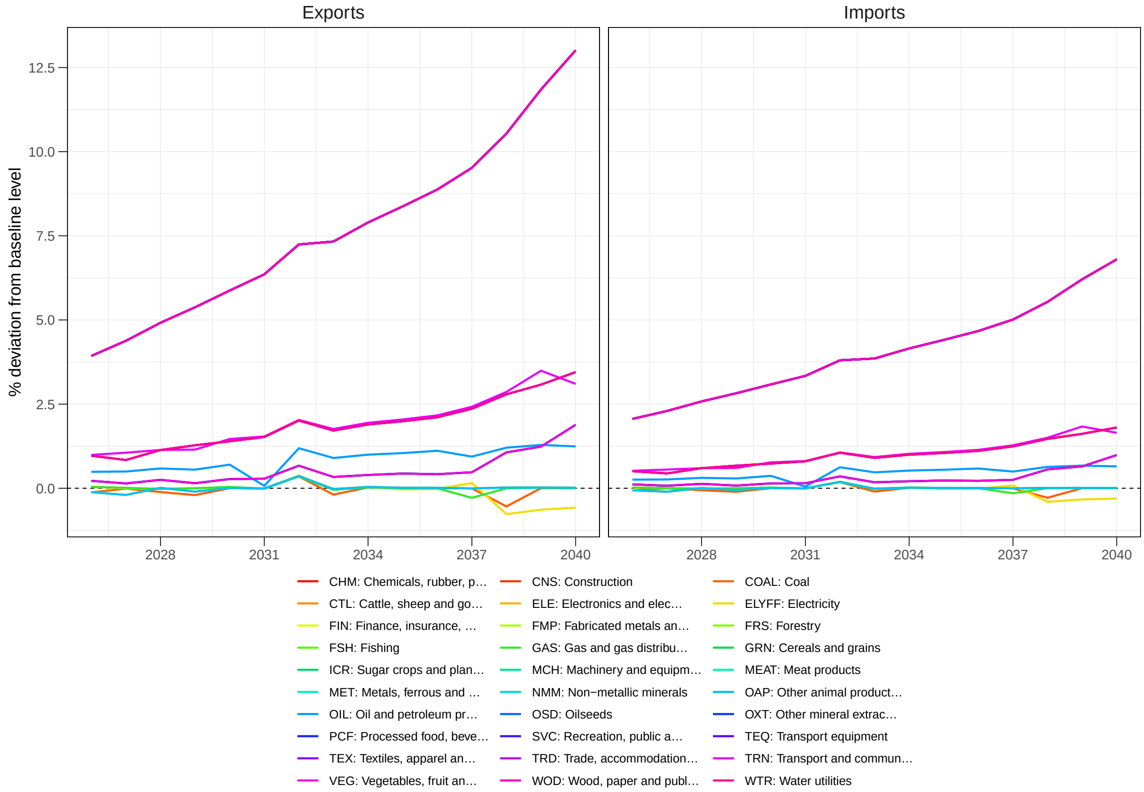

Figure 6.81: World import prices by commodity: deviation of real exports and imports from the baseline level, by lever.

6.4.4.2 World export prices by commodity

In the baseline real exports grow +5.01% a year and imports +5.03% a year over 2026–2040. Within this block the fastest export growth comes under **WOD — Wood, paper and publishing** (+5.52% a year) and the slowest under **COAL — Coal** (+4.76%); import growth is highest under **CHM — Chemicals, rubber, plastics, pharmaceuticals** (+5.30%) and lowest under **COAL — Coal** (+4.89%). A lever that raises export growth and lowers import growth is improving the trade balance; one that raises both is expanding trade at a roughly constant balance, which is the usual signature of a terms-of-trade or transfer gain spent partly on imports.

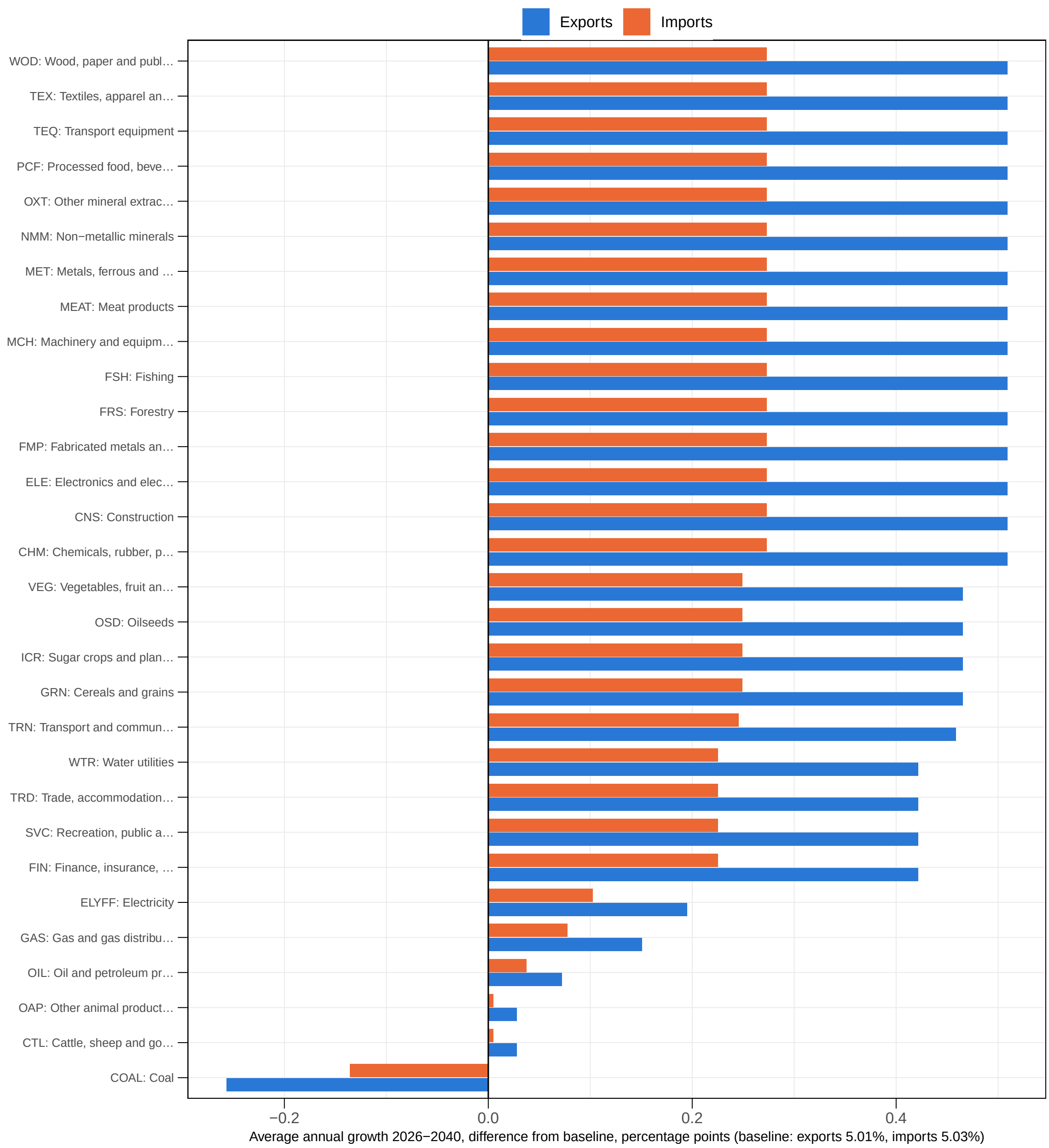

Figure 6.82: World export prices by commodity: average annual growth of real exports and imports over 2026–2040, difference from the baseline rate in percentage points, by lever.

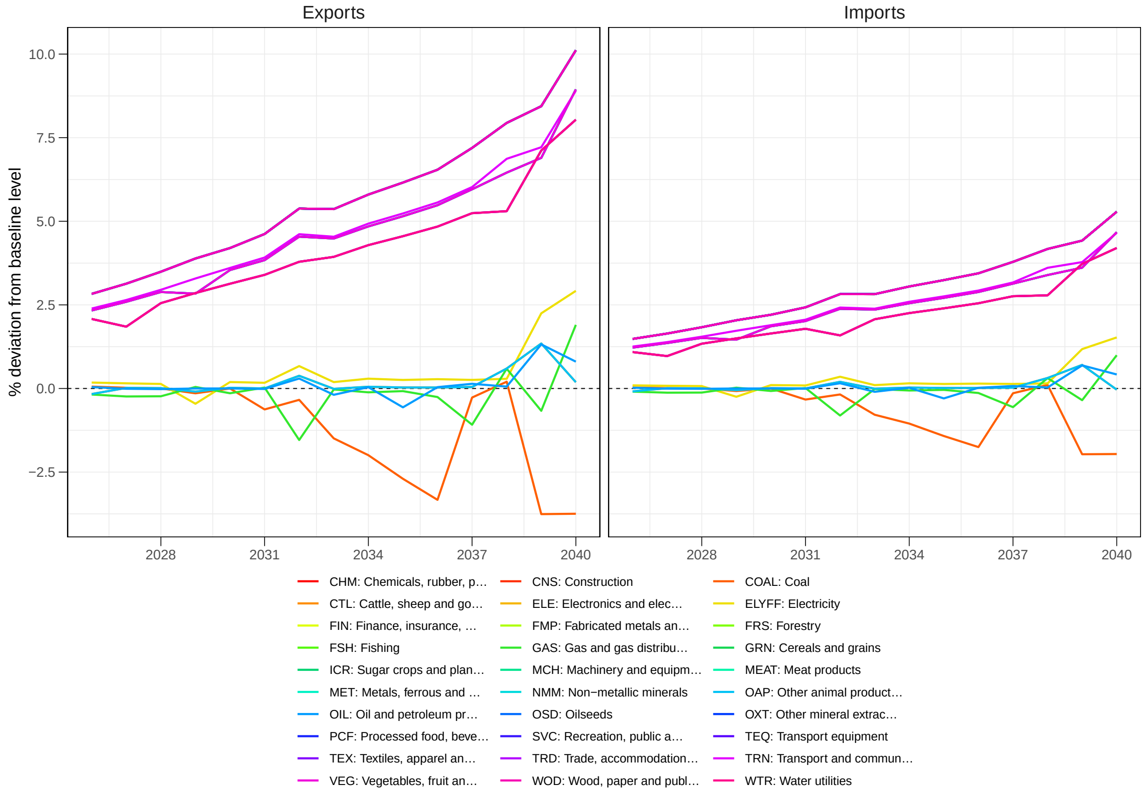

Figure 6.83: World export prices by commodity: deviation of real exports and imports from the baseline level, by lever.

6.4.4.3 Transfers and capital flows

In the baseline real exports grow +5.01% a year and imports +5.03% a year over 2026–2040. Within this block the fastest export growth comes under **Official development assistance to government** (+5.03% a year) and the slowest under **Remittances and current transfers** (+4.95%); import growth is highest under **Remittances and current transfers** (+5.22%) and lowest under **Foreign direct investment and net foreign saving** (+5.04%). A lever that raises export growth and lowers import growth is improving the trade balance; one that raises both is expanding trade at a roughly constant balance, which is the usual signature of a terms-of-trade or transfer gain spent partly on imports.

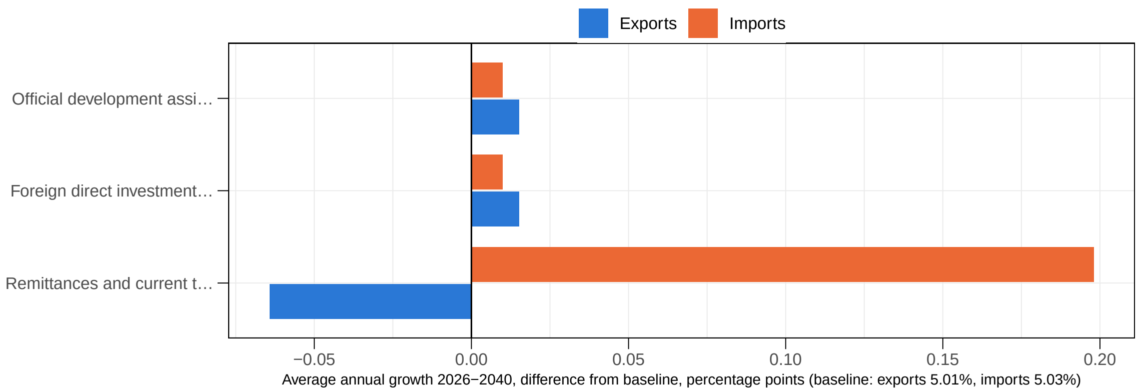

Figure 6.84: Transfers and capital flows: average annual growth of real exports and imports over 2026–2040, difference from the baseline rate in percentage points, by lever.

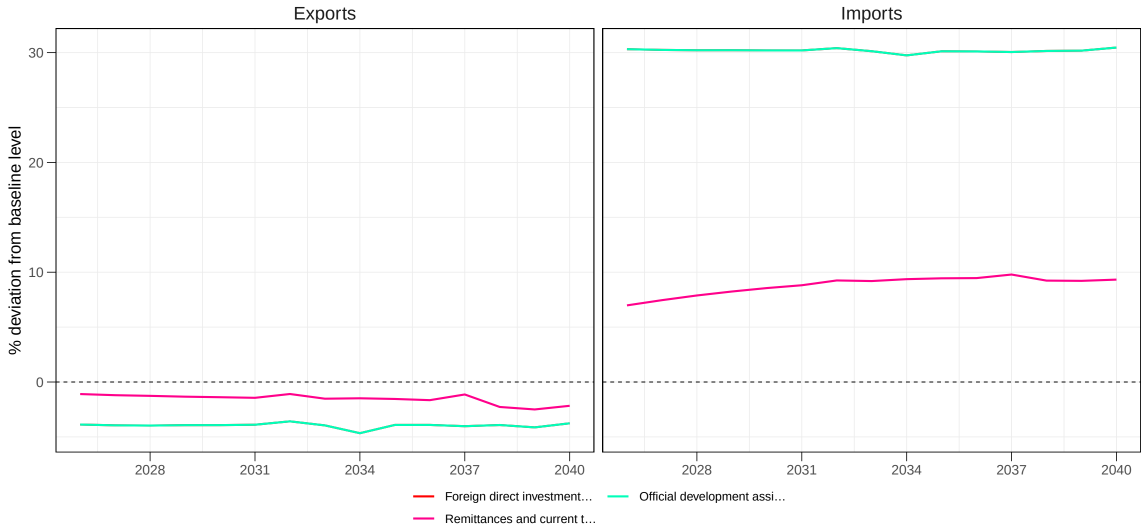

Figure 6.85: Transfers and capital flows: deviation of real exports and imports from the baseline level, by lever.

6.4.5 World prices: import and export sides compared

The two blocks above are reported as charts rather than as tables. Each carries thirty instruments and **nine distinct answers**: instruments naming medium-30 commodities are retargeted onto the nine sectors this build carries, and most then become the same shock. A thirty-row table makes a reader scan sixty lines to discover that repetition, where a chart shows it immediately.

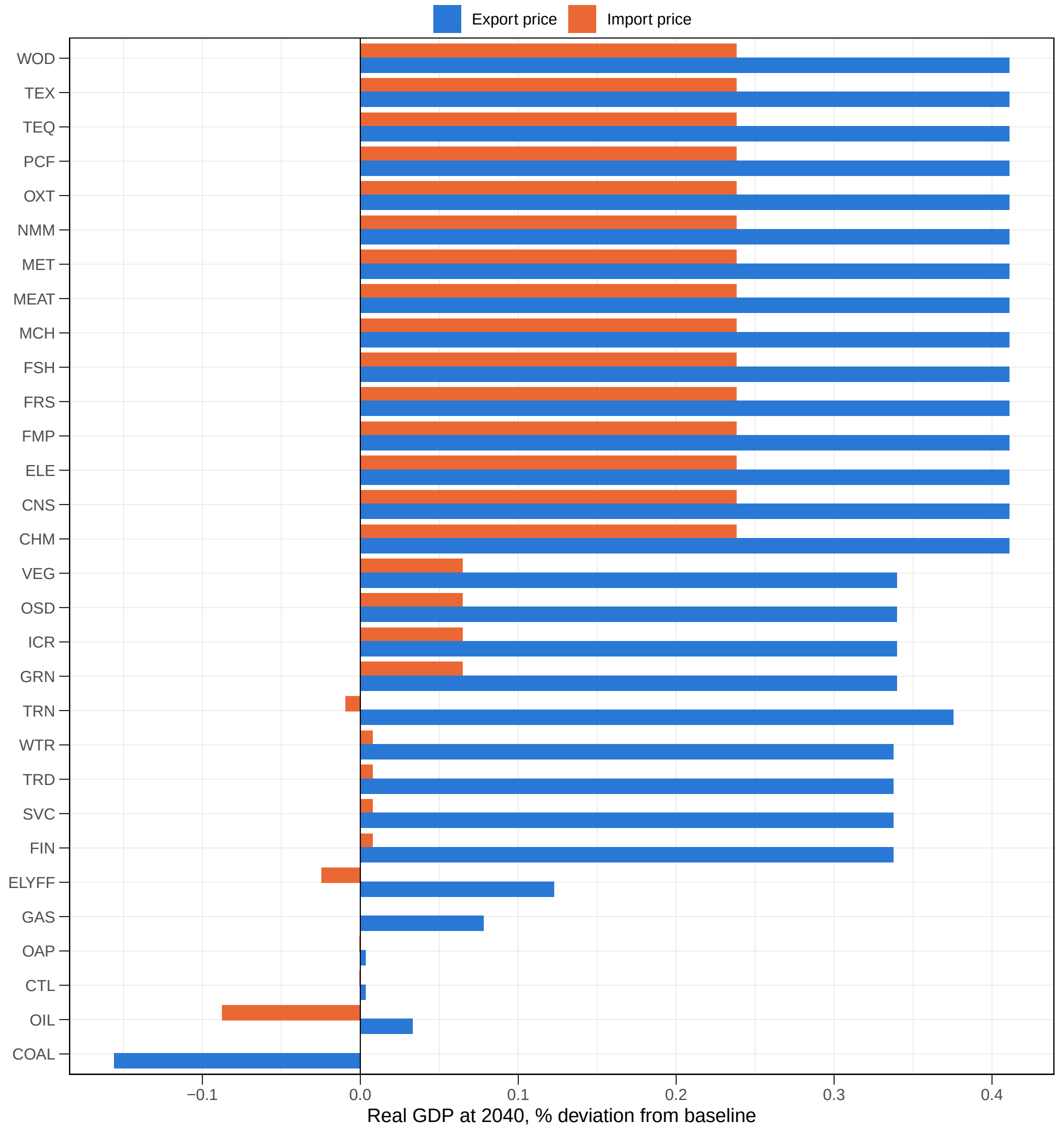

Figure 6.86: Real GDP at 2040 under a ten per cent rise in the world import price and in the world export price, by commodity.

6.4.5.1 Export prices move the economy further than import prices

Figure 6.86 shows the asymmetry directly. Across the thirty commodities, a ten per cent rise in the world *export* price returns a median GDP effect of +0.393 per cent against +0.152 for the same rise in the world *import* price — roughly two and a half times as much on an identical shock.

The closure explains it. When a world export price is supplied for a commodity, the model switches that commodity to *small-open-economy* pricing: the price is pinned to the world level and the quantity is demand-determined. A rise is then a direct terms-of-trade gain on everything the country sells. A world import price rise, by contrast, raises the cost of what the country buys and is partly offset by substitution towards domestic supply through the Armington nest. That substitution is an import-substitution response, not a welfare gain, which is why the welfare panel matters.

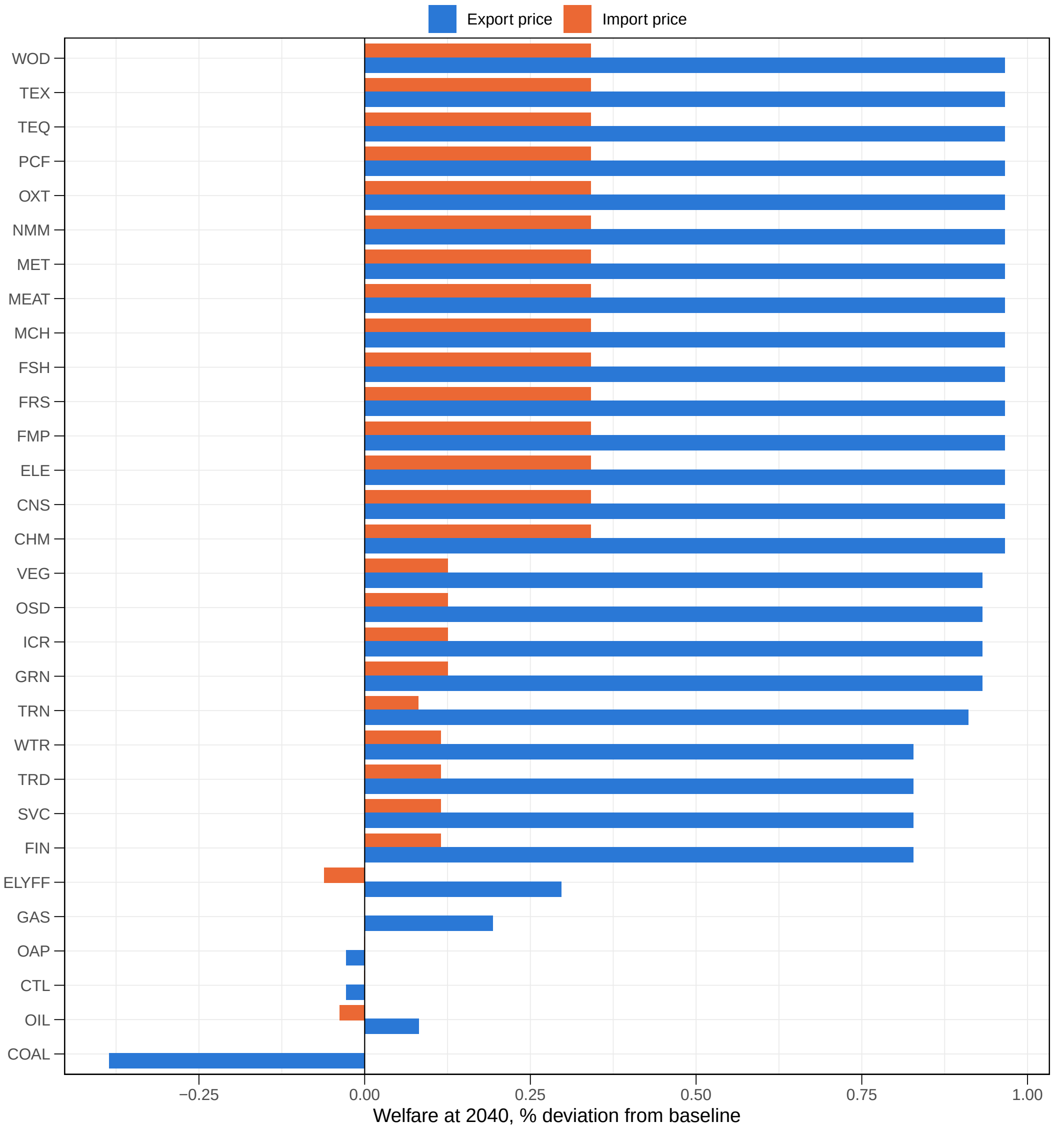

Figure 6.87: Welfare at 2040 under the same shocks. Welfare moves further than GDP on the export side and less far on the import side.

Figure 6.87 separates the two more sharply than output does. On the export side the median welfare effect is +0.949 per cent — more than twice the GDP effect — because a terms-of-trade gain raises real income without raising the cost of living. On the import side the median is +0.234 per cent against a GDP effect of +0.152: the gap is narrower, and for the commodities households actually consume it closes or reverses.

6.4.5.2 Which commodities go the other way

Six import prices reduce GDP: cattle, other animal products, oil, gas, electricity and transport. These are the commodities Uganda is a net importer of, or which enter as intermediates to everything else — a higher world price for transport or electricity raises a cost the whole economy pays and cannot substitute away from.

On the export side only **coal** is negative. A higher world coal price raises a cost the economy pays by more than a revenue it earns, which is the signature of a commodity the country buys rather than sells.

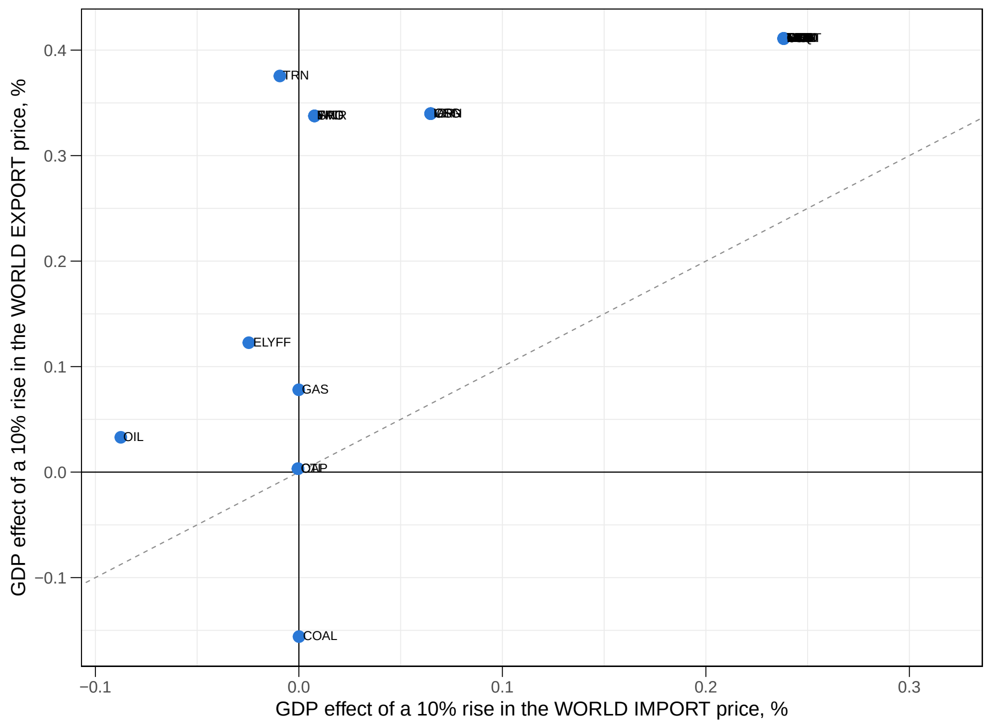

Figure 6.88: The import effect against the export effect for the same commodity. The dashed line is equal response; points above it are commodities the economy gains more from selling dearer than it loses from buying dearer.

Figure 6.88 plots the two sides against each other, one point per commodity. Almost every commodity sits above the 45-degree line, which is the general statement of the asymmetry: for this economy at these magnitudes, selling dearer is worth more than buying dearer costs.

6.4.5.3 What the ties mean

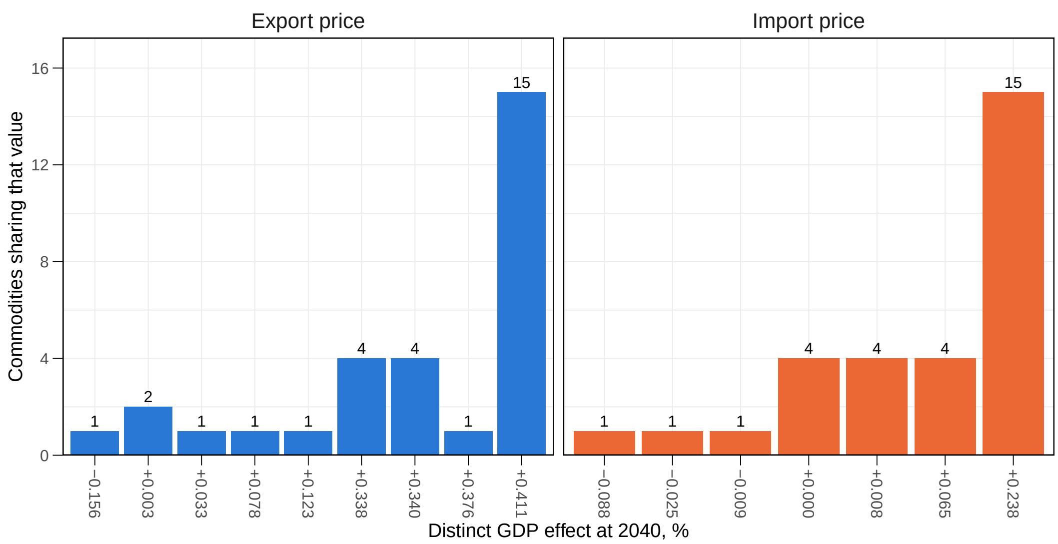

Figure 6.89: How many commodities share each distinct value. Nine distinct answers across thirty instruments, on each side.

Figure 6.89 is the caveat, charted. The tallest bar in each panel holds fifteen commodities returning one value, because at nine-sector resolution those fifteen fall into a single aggregate and a world price shock to any of them is the same shock.

This does not invalidate the results; it bounds what they can be asked. Two commodities sharing a bar are not evidence that their world prices matter equally — the model was not asked the question at a resolution that could separate them. A commodity-specific trade question needs the thirty-sector build, where the instruments separate. The nine-sector build is better conditioned for a twenty-four-year dynamic run, which is the trade-off set out in the calibration chapter of the model report.

6.5 Robustness

Four features underpin the robustness of these results.

First, the baseline is a genuine *balanced-growth path*. Because the calibrated model is homothetic in the exogenous levels, every benchmark quantity grows at one consistent rate, so a reported deviation is not an artefact of an unbalanced reference. The invariant behind it is that a neutral scenario — every lever at its default — feeds back exactly zero per cent, and the base year reproduces the benchmark exactly.

Second, every lever is compared with the *same* baseline, solved once. Differences across the table are therefore differences between policies rather than between solver trajectories.

Third, each annual equilibrium is solved with the PATH complementarity solver under a warm-start and cold-start recovery ladder, so a single stiff period cannot cascade into divergence. Periods the solver did not certify are recorded per run and reported with the results.

Fourth, the distributional results rest on a survey that is checked against its own published statistics: the micro-base reproduces the Uganda National Panel Survey's official poverty flag to within one percentage point, which is reported in the poverty chapter.

Results should nonetheless be read as *directional and comparative* across levers rather than as point forecasts, and sensitivity to the chosen shock intensity and timing can be explored directly on the platform[2].

6.5.1 What the resolution can and cannot separate

The instruments that name individual commodities are applied to a nine-sector build, and are retargeted through the commodity remap before they reach the model. Instruments whose commodities fall into the same sector become the same shock. That is visible in the tables as tied values, and quantified at the head of each chapter.

This does not invalidate the results. It means two tied rows are not evidence that two policies are equivalent — the question was asked at a resolution that cannot tell them apart. A commodity-specific tax or trade question needs the thirty-sector build, where the instruments separate; the nine-sector build is better conditioned for a twenty-four-year dynamic run, which is the trade-off the calibration chapter of the model report sets out.

6.6 Levers and prioritisation

This chapter synthesises all **209 levers** simulated across 19 groups and prioritises them by their general-equilibrium impact at 2040. Prioritisation follows the logic of ranking interventions by their contribution to the growth objective[3]; the highest-return lever is **Digital infrastructure** (Transport infrastructure, +16.65% GDP at 2040).

[2] On recursive-dynamic CGE practice and interpretation see P.B. Dixon & M.T. Rimmer, *Dynamic General Equilibrium Modelling for Forecasting and Policy*, North-Holland, 2002.

[3] On growth diagnostics and the prioritisation of binding constraints and high-return interventions see R. Hausmann, D. Rodrik & A. Velasco, “Growth Diagnostics”, in *The Washington Consensus Reconsidered*, Oxford University Press, 2008.

6.6.1 Master ranking of levers

The table ranks the top levers across every group by their 2040 deviation from the balanced-growth baseline; the chart shows the same ranking graphically.

#	Lever	Group	%GDP 2040	%Welfare 2040
1	Digital infrastructure	Transport infrastructure	+16.65	+15.69
2	New mine investment	Mining and extraction	+14.92	+15.44
3	Aquaculture expansion	Forestry and fisheries	+13.35	+13.67
4	Mineral beneficiation	Mining and extraction	+11.21	+11.40
5	Plantation forestry	Forestry and fisheries	+10.03	+10.04
6	Agro-processing expansion	Manufacturing	+10.03	+10.04
7	Textiles and apparel upgrading	Manufacturing	+9.55	+9.70
8	Wood and panel processing	Forestry and fisheries	+8.88	+8.85
9	Tourism expansion	Services	+8.71	+8.24
10	Water and sanitation	Transport infrastructure	+8.61	+8.03
11	Economy-wide digital adoption	ICT and the digital economy	+8.31	+8.06
12	Dairy and meat processing	Livestock	+8.27	+8.17
13	Cold-chain investment	Livestock	+7.69	+7.59
14	Construction capacity	Transport infrastructure	+7.69	+7.59
15	Logistics and freight services	Transport infrastructure	+7.63	+6.88

Table 6.18: The fifteen highest-return levers by 2040 GDP impact, all groups.

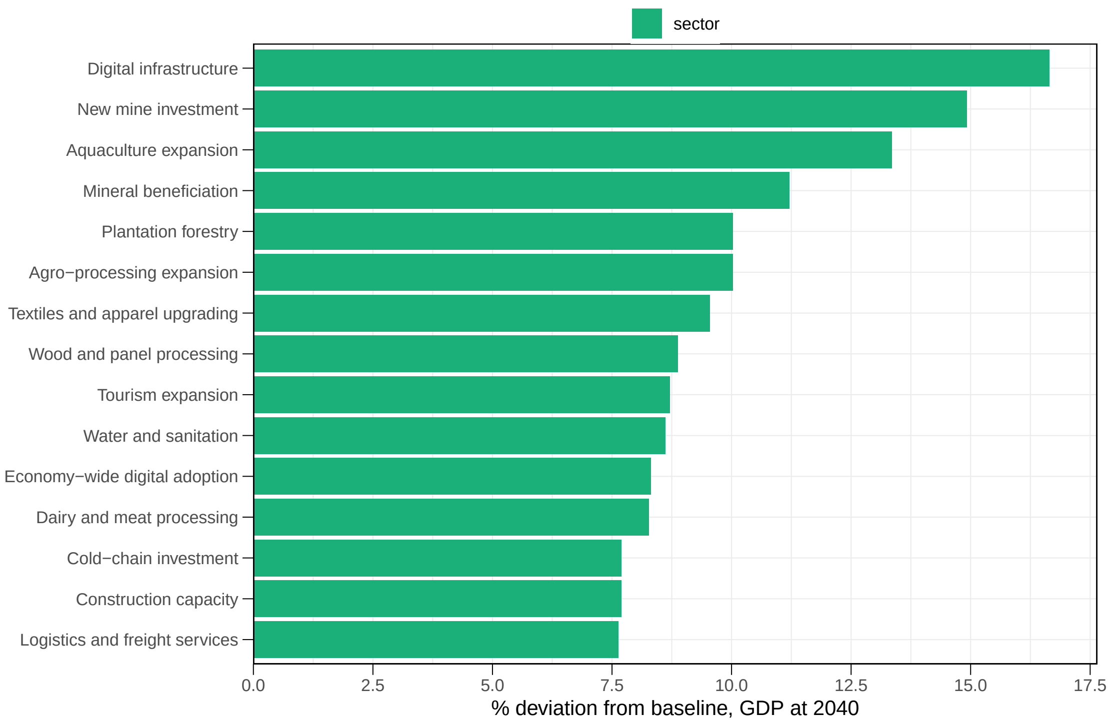

Figure 6.90: The highest-return levers by 2040 GDP impact.

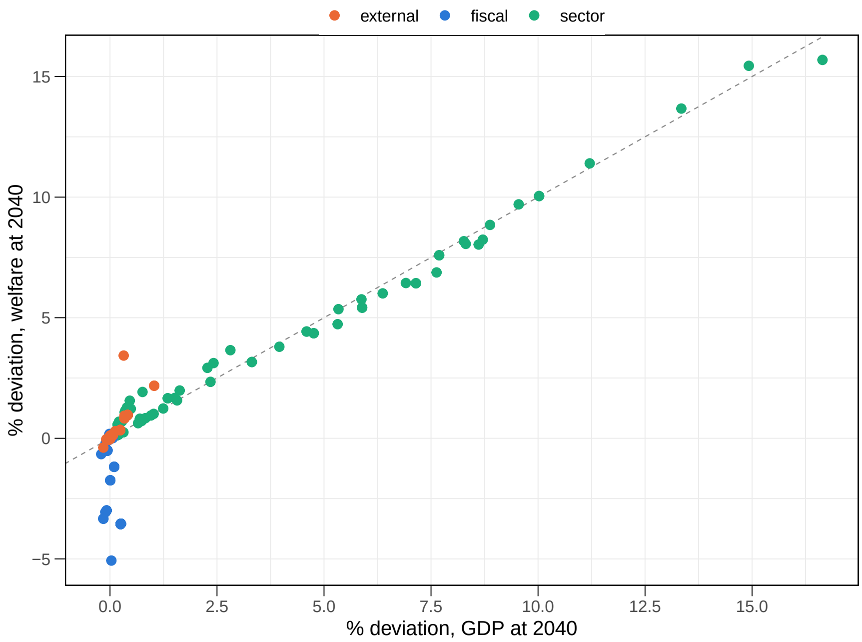

Figure 6.91: GDP against welfare at 2040, every lever. The dashed line is equal movement; points above it raise welfare by more than output.

6.6.2 Prioritisation and sequencing

Priority levers. Digital infrastructure (+16.65% GDP, +15.69% welfare); New mine investment (+14.92% GDP, +15.44% welfare); Aquaculture expansion (+13.35% GDP, +13.67% welfare).

The recommended sequence is to begin with the highest-return levers above, pairing productivity-raising measures with the enabling infrastructure and human capital they require, and to revisit the ranking as costs and financing are refined.

Two cautions attach to that advice and neither is optional. Because these effects are estimated in general equilibrium they already embed spillovers across sectors, trade and welfare; but they are *standalone* lever effects and **they are not additive**. The model is non-linear and productivity levers compound, so a package of six levers is not the sum of six rows from these tables. The poverty chapter quantifies that interaction for the packages that were also run separately.

And a ranking by output is not a ranking by poverty reduction. The distributional chapter shows the two orderings differ sharply — the largest GDP gain in the study is not the largest reduction in the headcount, and the lever that reduces poverty most is not in the top five by output. A programme judged on living standards should be prioritised on the distributional table, not on this one.

6.7 Poverty and income inequality

6.7.1 Poverty and inequality in Uganda: the starting point

Before the simulated distributions, the measured one. Uganda's national poverty headcount has fallen from 56.4 per cent in 1992 to 16.1 per cent in the 2023/24 National Household Survey, the eighth in the series, which surveyed 17,350 households; the number of people below the line fell from 8.3 to about 7 million in the five years to 2023/24 alone [300, 278]. On the World Bank's international line of $3.00 a day at 2021 purchasing power the picture is far less flattering — 59.8 per cent in 2019, and about 76 per cent below the $4.20 lower-middle-income line — because the national line sits well below the international one [361, 377]. Figure 6.92 plots all three. The national series is not monotonic: it rose between 2012 and 2016 and again in 2019/20, and the long decline is the sum of a fast fall in the 2000s and slower progress since.

Inequality has moved less. The Gini index has stayed between 39 and 45 since 1992 and stood at 0.413 in 2019/20; the 2023/24 survey puts it at 0.382, with 0.351 in rural and 0.384 in urban areas, and the Independent reads that as a narrowing of the gap while poverty persists in pockets [300, 273]. The top tenth of the population has taken about a third of income throughout (Figure 6.93).

The pockets are the point. Rural poverty is 19.4 per cent against 10.3 in towns; Karamoja's headcount *rose* from 65 to 74.2 per cent between the two surveys while the national rate fell, and Bukedi, Busoga and Acholi remain far above the average [69, 278]. Against its neighbours (Figure 6.94) Uganda's international-line headcount is above Kenya's and Ghana's and close to Tanzania's and Rwanda's, while its Gini is in the middle of the group. This is the distribution the microsimulation starts from, drawn from the 2019/20 panel that follows the same households, and it is the baseline against which every package in this chapter is measured.

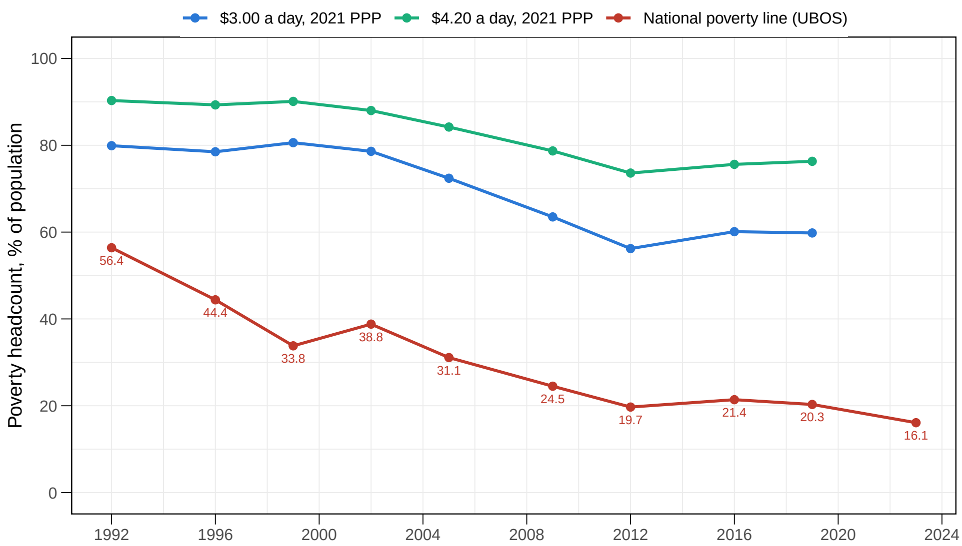

Figure 6.92: Poverty headcount in Uganda, 1992–2023/24: the national line (UBOS), the $3.00 and $4.20 a day international lines at 2021 PPP (World Bank).

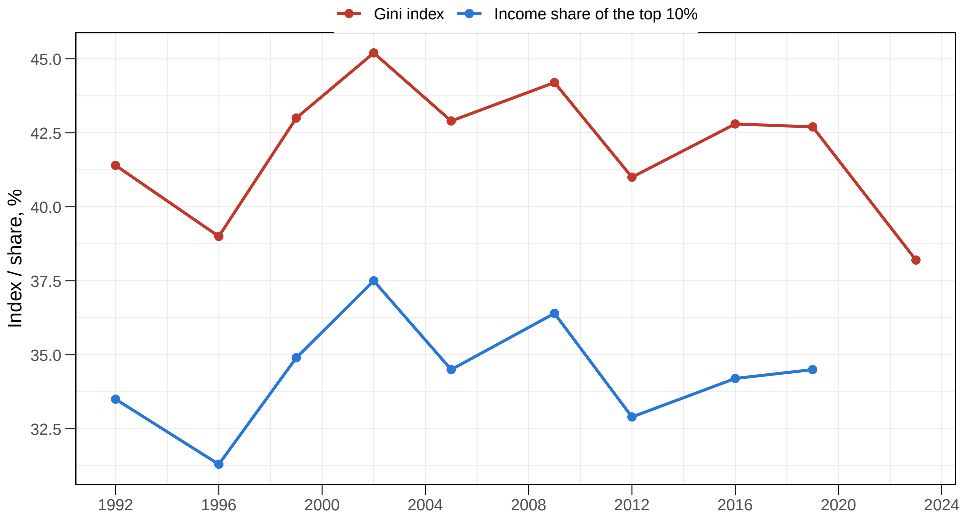

Figure 6.93: Inequality in Uganda, 1992–2023/24: the Gini index and the income share of the top ten per cent (World Bank; UNHS 2023/24 for the last point).

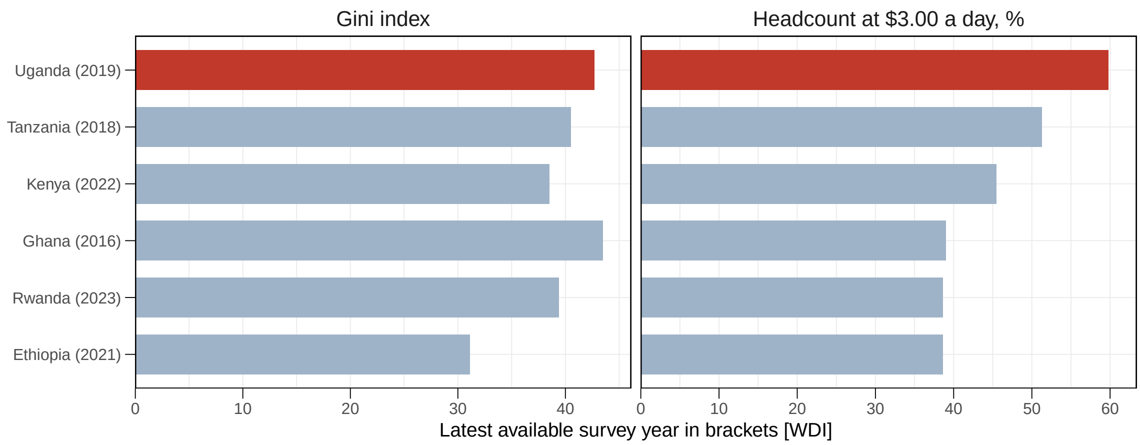

Figure 6.94: Uganda against its neighbours: headcount at $3.00 a day and the Gini index, latest survey year (World Bank).

6.7.2 Growth and poverty are not the same ranking

Figure 6.95 is the central figure of this report. If growth and poverty reduction were the same thing, the packages would lie on a downward line. They do not.

The **ICT** package raises real GDP by 33.0 per cent and cuts the headcount by 7.63 percentage points. The **agriculture** package raises GDP by 8.3 per cent — a quarter as much — and cuts the headcount by 9.24 points, which is *more*. And the colour separates them further: agriculture is the only package in the set that lowers the Gini, by 0.027, while ICT raises it by 0.017.

Figure 6.96 states the same result as an elasticity. Agriculture returns −6.07: each additional per cent of GDP cuts the headcount by about six per cent of its baseline level. ICT returns −1.26 and manufacturing −0.82. Agriculture is therefore roughly **five times** more poverty-reducing per unit of growth than ICT and **seven times** more than manufacturing.

6.7.2.1 How this sits against the evidence

This is not a novel result and it should not be read as one. It is one of the better-established regularities in development economics, and the model reproducing it is a point in the model's

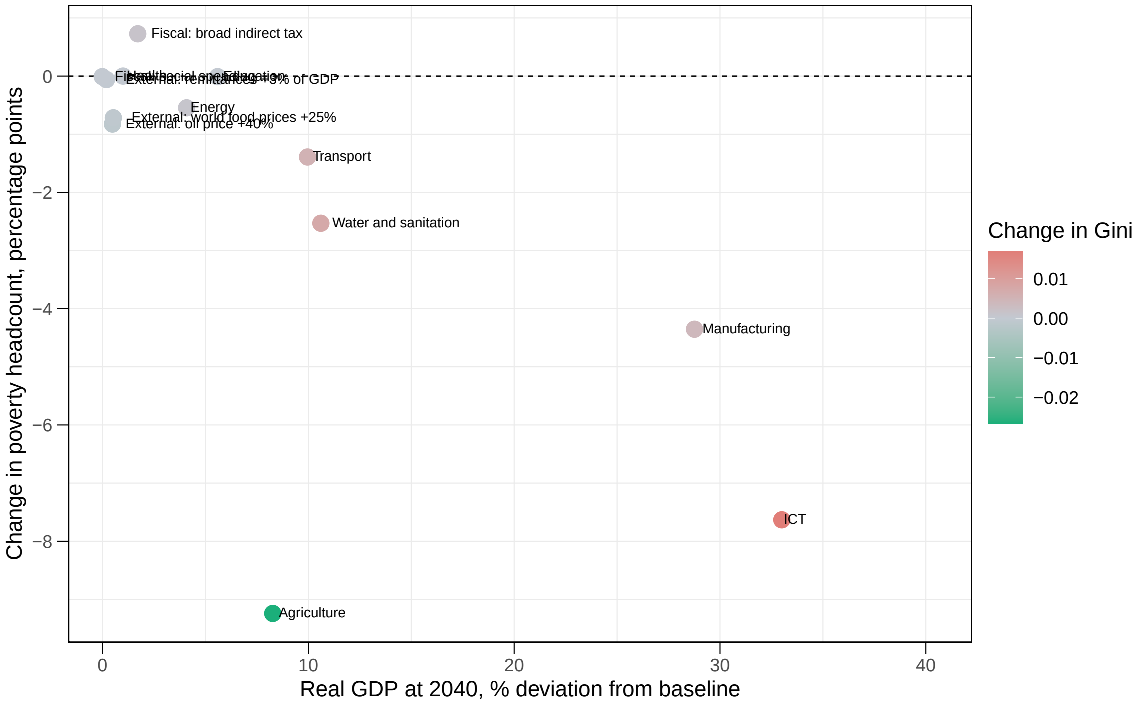

Figure 6.95: Each policy package plotted by its effect on real GDP (horizontal) and on the poverty headcount (vertical) at 2040. Colour shows the change in the Gini coefficient: green is a fall in inequality, red a rise.

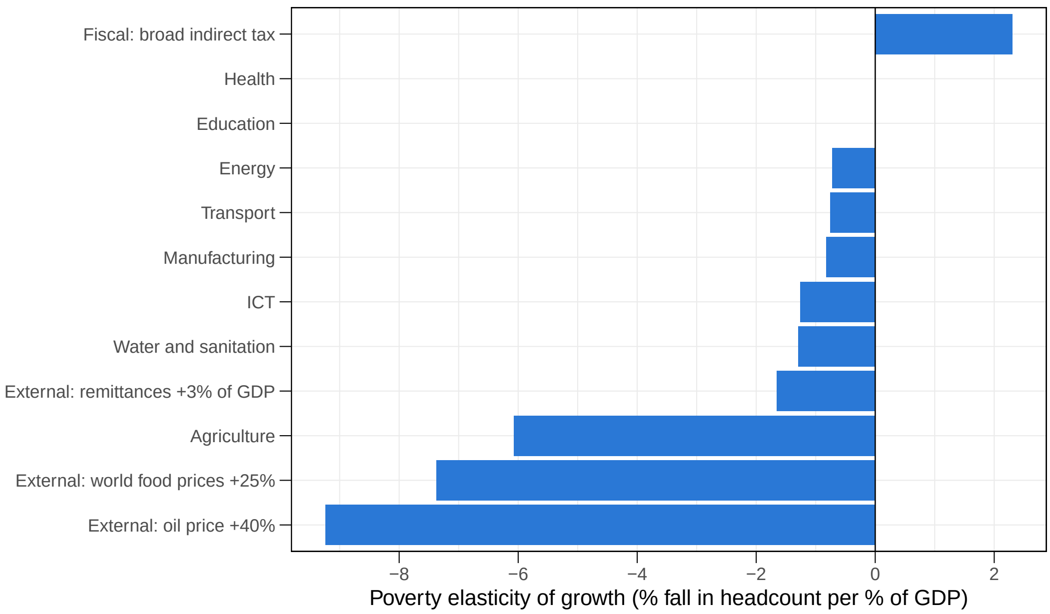

Figure 6.96: The poverty elasticity of growth by package: the percentage fall in the headcount per percentage point of additional GDP. More negative is more poverty-reducing per unit of growth.

favour rather than a discovery.

Christiaensen, Demery and Kühl, in *The (Evolving) Role of Agriculture in Poverty Reduction — An Empirical Perspective* (*Journal of Development Economics* 96(2), 2011, 239–54), estimate cross-country that growth originating in agriculture is substantially more poverty-reducing than growth of the same size originating elsewhere. The figure usually quoted from that literature is that agricultural growth is around **three times** more effective at reducing poverty than growth in other sectors, and that the advantage is largest in low-income countries where the poor are concentrated in agriculture and participate in its growth directly.

The model here returns a ratio nearer five. Three things plausibly account for the gap, and each is a caveat on the number rather than a defence of it:

- **The microsimulation transmits food prices as well as incomes.** An agricultural productivity gain lowers the relative price of food, and food is the largest single item in the budget of a poor Ugandan household. The consumer-price channel therefore reinforces the income channel. In the cross-country regressions this shows up only to the extent that the price effect is already in the observed poverty series.
- **The elasticity here is measured at a single horizon under one closure.** Foreign saving is exogenous in this model and the real exchange rate clears the balance of payments, which is a strong assumption over twenty-four years.
- **The distribution being re-weighted is Uganda's, not an average country's.** Uganda's poor are unusually agricultural even by low-income standards, so a high elasticity is what one would expect *for Uganda* rather than for the cross-country mean the literature estimates.

The direction and the ordering are the robust part. The precise ratio is not.

6.7.2.2 Why ICT raises inequality

The ICT result also has a literature behind it, and it is a different one. ICT and digital adoption in developing countries is generally found to be *skill-biased*: it raises the return to skilled labour relative to unskilled, because the technologies complement education and substitute for routine unskilled tasks. Empirical work on developing countries finds that the effect of ICT adoption on labour-market participation is negative for household heads with little or no formal schooling and turns positive only well into post-secondary education.

That is precisely the mechanism the microsimulation carries. The CGE hands it a wage change *by skill*, and the behavioural pass redraws each household's occupation and income against it. A package that raises the skilled wage faster than the unskilled wage will raise measured inequality regardless of how much aggregate output it produces — and Figure 6.95 shows exactly that pattern, with ICT posting the largest GDP gain in the set and a rising Gini.

The policy reading is not that ICT investment is a mistake. It is that an ICT package and an agriculture package are answers to different questions, and a programme judged on the headcount will rank them differently from one judged on output. The literature's own policy conclusion — that digital investment needs to be paired with education and digital-skills provision if it is not to widen gaps — is consistent with what the model shows.

6.7.3 The distribution itself

Figure 6.97 shows why a single inequality index is not enough. Two distributions can share a Gini and cross; the curve shows where in the distribution a policy acts. The agriculture curve lies inside the baseline over most of its range — unambiguously less unequal — while ICT lies outside it.

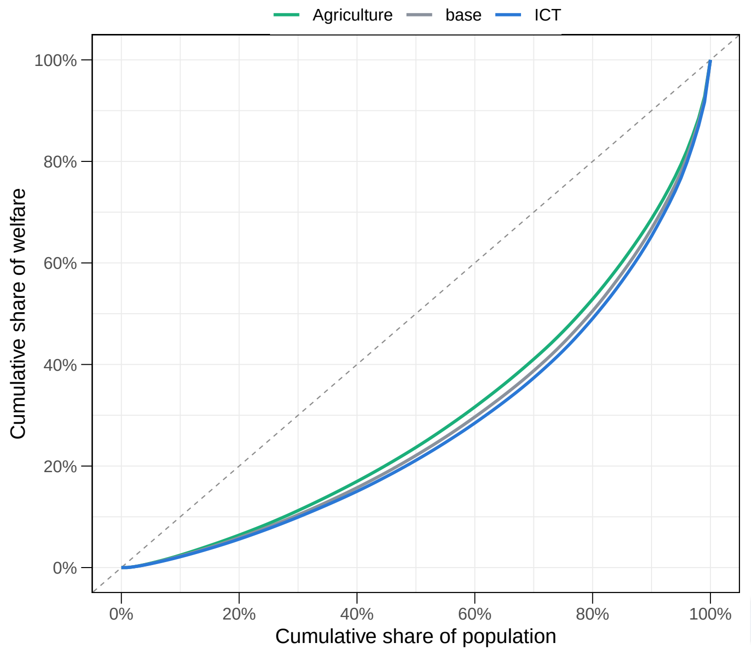

Figure 6.97: Lorenz curves at 2040. The dashed diagonal is perfect equality; a curve further from it is a more unequal distribution.

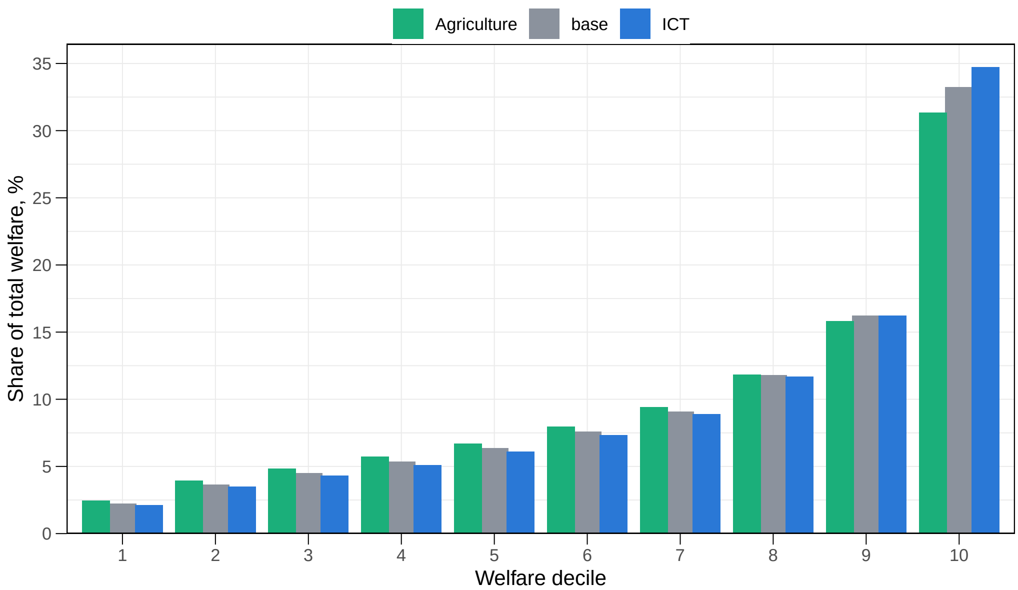

Figure 6.98: Share of total welfare held by each decile at 2040.

Figure 6.98 is the same information without the cumulation, which makes the bottom deciles legible. A policy is usually judged on the bottom tenth rather than on a summary statistic, and the decile chart is where that is visible.

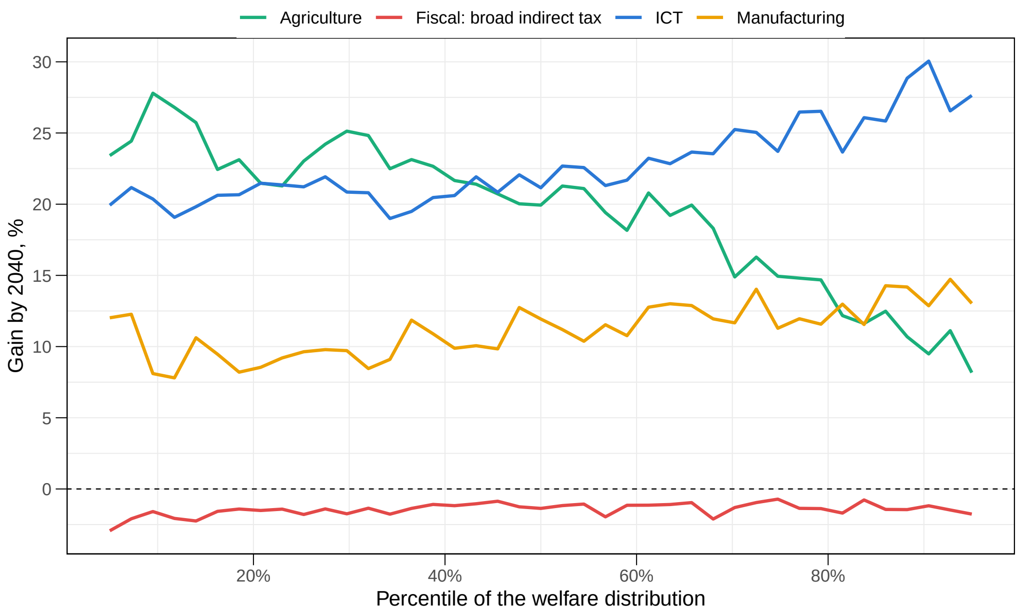

Figure 6.99: Growth incidence curves: the gain by 2040 at each percentile of the welfare distribution. A downward-sloping curve is pro-poor in the relative sense — the poor gain proportionally more than the average.

Figure 6.99 is the growth incidence curve of Ravallion and Chen, and it is the most informative single diagnostic in the set. The curve plots the proportional gain at each percentile. A *downward slope* means the poor gained proportionally more than the rich; a flat curve means distribution-neutral growth; an upward slope means the gains accrued to the top.

This is also where the two concepts of pro-poor growth part company, and the report reports both because they can disagree:

- The **relative** definition (Kakwani and Pernia) asks whether the poor gained *more than the average*. On this definition a package with a downward-sloping incidence curve is pro-poor even if the absolute gains are small.
- The **absolute** definition (Ravallion and Chen) asks whether the poor gained at all, and by how much. On this definition a package with large uniform gains can be pro-poor while a package with tiny but disproportionately-poor gains is not.

Figure 6.109 reports the mean growth rate, the Kakwani–Pernia index and the poverty-equivalent growth rate side by side for this reason. A reader who takes only one of them is choosing a distributional objective without saying so.

6.7.4 Is the result robust to where the line is drawn?

A headcount is a statement about a line as much as about a policy. Figure 6.100 removes that dependence by plotting the headcount at every line from a quarter of the national line to twice it.

Of the twenty-two packages, eleven dominate the baseline at first order — poverty is lower at every line in the range, so the conclusion does not depend on the choice — nine have crossing curves, and two are dominated. A crossing is not a failure of the analysis; it is a finding. It

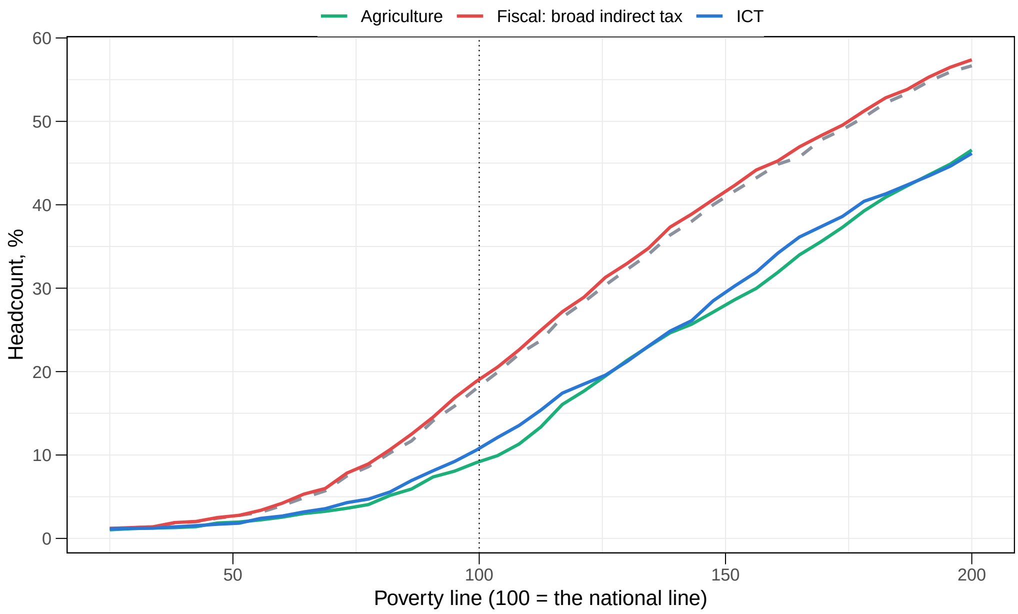

Figure 6.100: First-order poverty dominance. Each curve is the headcount at every poverty line over the range, not only at the national line (dotted). Where a policy curve lies below the baseline across the whole range, poverty fell for any line one might choose.

says the sign of the poverty effect depends on where the line sits, and a report quoting a single headcount for such a package would be presenting a choice of line as a result.

First-order dominance covers every poverty line. Second-order dominance, also tested and charted in Figure 6.110, additionally covers every distribution-sensitive poverty index — so a package that dominates at second order cannot be overturned by preferring Watts or the squared gap to the headcount.

Figure 6.101 shows why the report carries more than the headcount. The three FGT indices answer different questions, and a policy can move them in different directions: lifting many households just across the line moves FGT_0 sharply and FGT_2 barely, while raising the very poorest without crossing the line does the opposite. Watts and the Sen–Shorrocks–Thon index, reported in the tables, are distribution-sensitive in the same way. Where they disagree with the headcount, the disagreement is the finding.

Figure 6.102 reports the inequality battery. The indices are not interchangeable: the Gini is most sensitive around the middle of the distribution, the Atkinson index at high ε and generalised entropy at $\theta = 0$ weight the bottom hardest, and the coefficient of variation is driven by the top tail. A package that compresses the middle while stretching the top will move them in different directions, which is why all of them are reported rather than one.

6.7.5 What the method can and cannot deliver

The distributional results in this report come from a *top-down* linkage: the CGE is solved first, and its wage, employment, self-employment and consumer-price changes are passed to a microsimulation that redraws each household. The household side does not feed back into the CGE.

This is the standard arrangement in the CGE–microsimulation literature, and its properties are well documented. The top-down design with behaviour — as distinct from simple micro-accounting without behaviour — allows occupational choice and earnings to respond to the macro shock, which is what makes the distributional answer more than a re-weighting exercise. Bourguignon, Robilliard and Robinson set out the specification and data-reconciliation problems

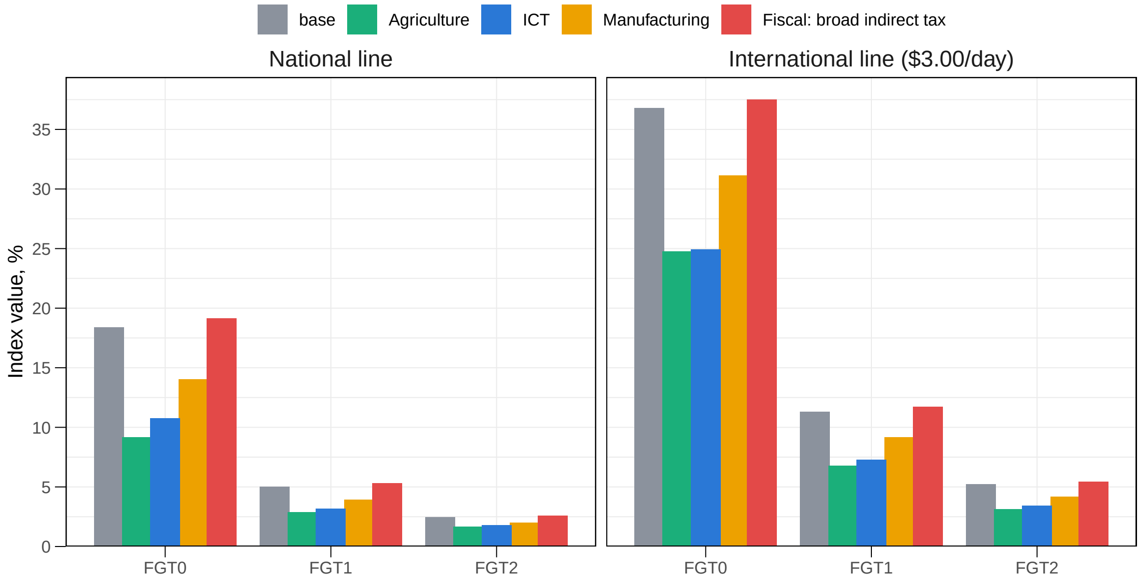

Figure 6.101: The FGT family at both poverty lines. FGT_0 counts the poor, FGT_1 weights them by how far below the line they are, FGT_2 by the square of that distance.

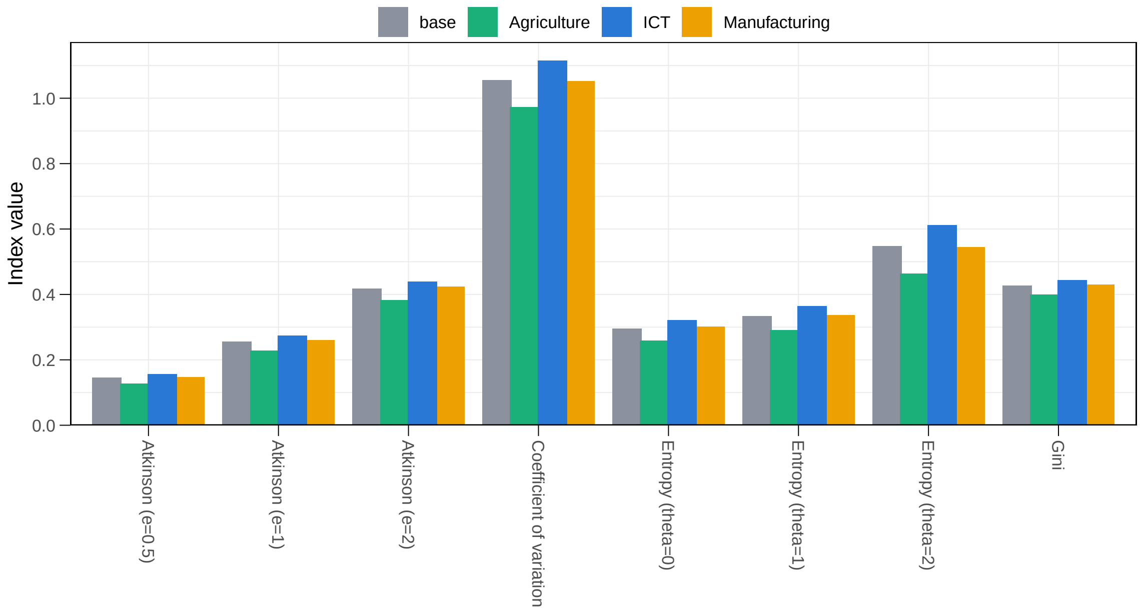

Figure 6.102: Inequality indices at 2040. Atkinson at high inequality aversion and generalised entropy at $\theta = 0$ weight the bottom of the distribution most heavily.

that any such linkage has to confront, and those problems have not gone away.

The specific toolkit used here is **TDBmicrosim**, the top-down behavioural microsimulation toolkit developed in the PEP (Partnership for Economic Policy) network at Université Laval, with distributive indices computed by **DASP** — the Distributive Analysis Stata Package — through its R port `daspr`.

Three limits follow directly from the design, and they bound every number in this chapter:

- **No feedback.** Because the linkage is one-directional, changes in household consumption and labour supply do not return to the CGE. A top-down/bottom-up iterative scheme would close that loop; this one does not, and the results should be read as the distributional *incidence* of a given macro path rather than as a jointly determined equilibrium.
- **The distribution is the survey's.** The micro-base is Uganda's National Panel Survey 2019/20. The simulation asks what a scenario does to that distribution. Structural change in the distribution itself over twenty-four years — urbanisation, changes in household formation, sectoral shifts in employment beyond those the model transmits — is not represented.
- **Simulated levels sit above observed ones.** Re-simulating occupation and income for every household adds dispersion the survey does not have. The survey's own distribution yields a headcount of 14.5 per cent; the simulated baseline at 2040 yields 18.4 per cent. The comparison between two simulated scenarios is the answer; the simulated level on its own is not an estimate of poverty in 2040.

This section leans on published empirical and methodological work, listed with everything else in the References: on agriculture's weight in poverty reduction [46, 45]; on the measurement of pro-poor growth [243, 169]; on the FGT family [124]; on representative against real households in macroeconomic modelling [35] and on microsimulation as an instrument of policy evaluation [32]; on the index battery the results are computed with [23] and the toolkit that produces the distributions [22]; and on the skill bias of technical change [160]. Where this report's numbers agree with that literature, the agreement is a check on the model; where they differ — as with the size of the agricultural poverty elasticity — the difference is stated and its likely causes given, rather than the model's figure being presented as a correction to the literature.

6.7.6 The policy packages

The distributional pass runs on PACKAGES rather than on individual levers. Running it on all 209 would take about a day of computation, and a single lever at intensity 1.0 moves the distribution too little to decompose. A package is also the shape a real programme takes.

Figure 6.103 sets out the 22 packages by their macroeconomic effect at 2040, GDP beside real consumption. The strongest is **Forestry and fisheries** (+37.87% GDP, +37.24% real consumption) and the weakest **External: export price collapse -25%** (-1.42% GDP). Where the two bars part company the package is moving a price wedge rather than output: the widest gap is under **Fiscal: broad indirect tax**, where GDP moves by +1.72% but real consumption by -25.35%, the mark of a package that shifts resources from households to the government or abroad. It is real consumption, not GDP, that reaches the microsimulation.

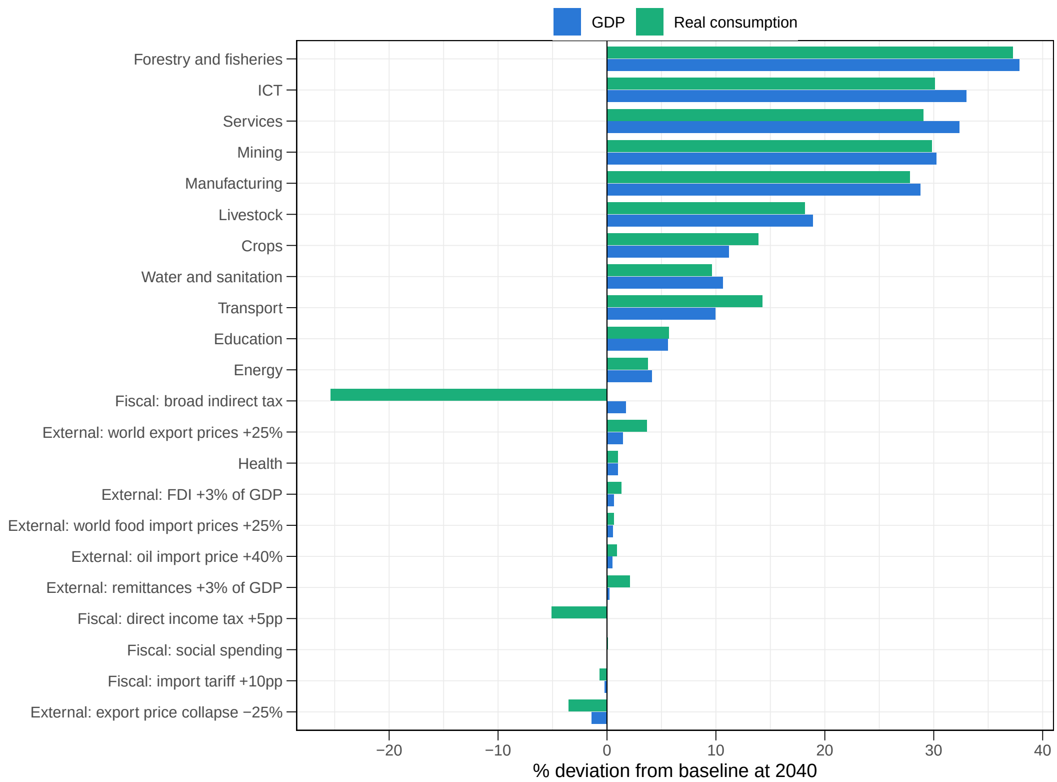

Figure 6.103: Policy packages: GDP and real consumption at 2040, % deviation from baseline.

6.7.7 Poverty at the national line

At the national line the simulated 2040 baseline headcount is 18.4 per cent. Of the 22 packages, 17 leave it below that. The largest reduction is under **Crops** (6.6 per cent, -11.8 points); the highest headcount is under **Fiscal: broad indirect tax** (19.1 per cent, +0.7 points). Figure 6.104 charts the full FGT family, the Watts index and the Sen–Shorrocks–Thon index with 95 per cent confidence intervals; the dashed line in each panel is the baseline. The ordering is broadly the same across the five panels: a package that removes the most people from poverty also removes the most depth and severity, so the choice of index does little to the ranking.

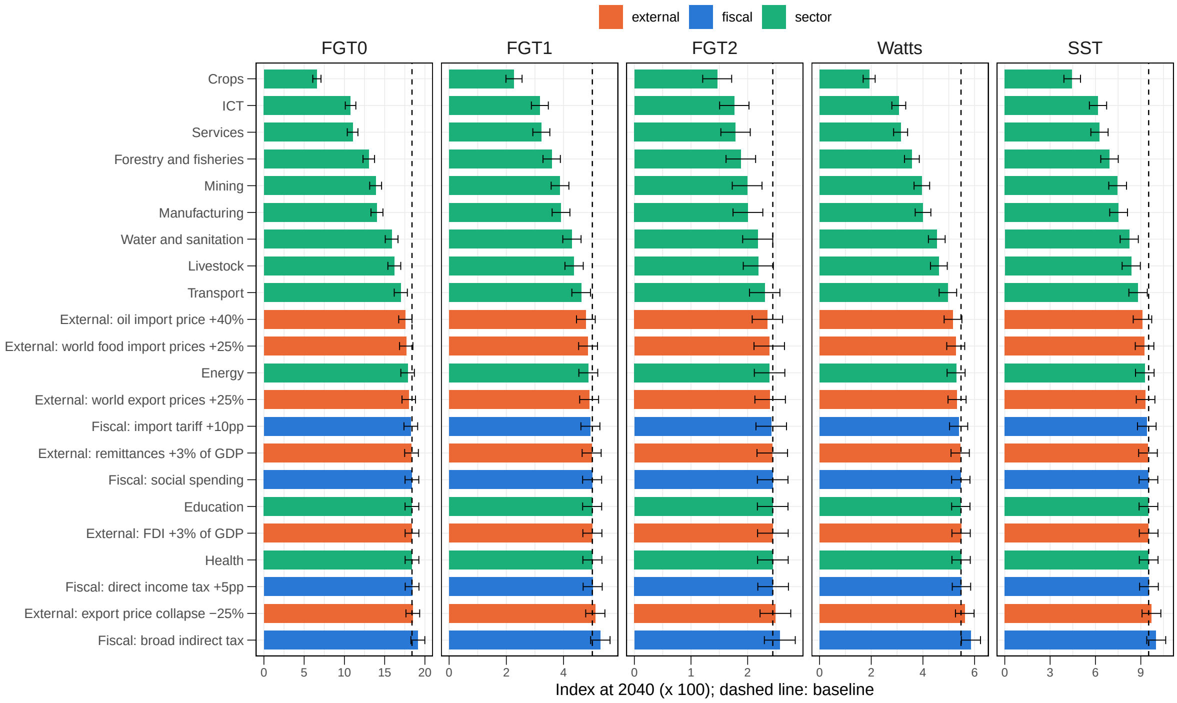

Figure 6.104: Poverty at the national line at 2040 by scenario: FGT_0, FGT_1, FGT_2, Watts and SST ($\times 100$) with 95 per cent confidence intervals. Dashed line: baseline.

6.7.8 Poverty at the international line

At the international line the simulated 2040 baseline headcount is 36.8 per cent. Of the 22 packages, 19 leave it below that. The largest reduction is under **Crops** (19.0 per cent, -17.7 points); the highest headcount is under **Fiscal: broad indirect tax** (37.5 per cent, +0.7 points). Figure 6.105 charts the full FGT family, the Watts index and the Sen–Shorrocks–Thon index with 95 per cent confidence intervals; the dashed line in each panel is the baseline. The ordering is broadly the same across the five panels: a package that removes the most people from poverty also removes the most depth and severity, so the choice of index does little to the ranking.

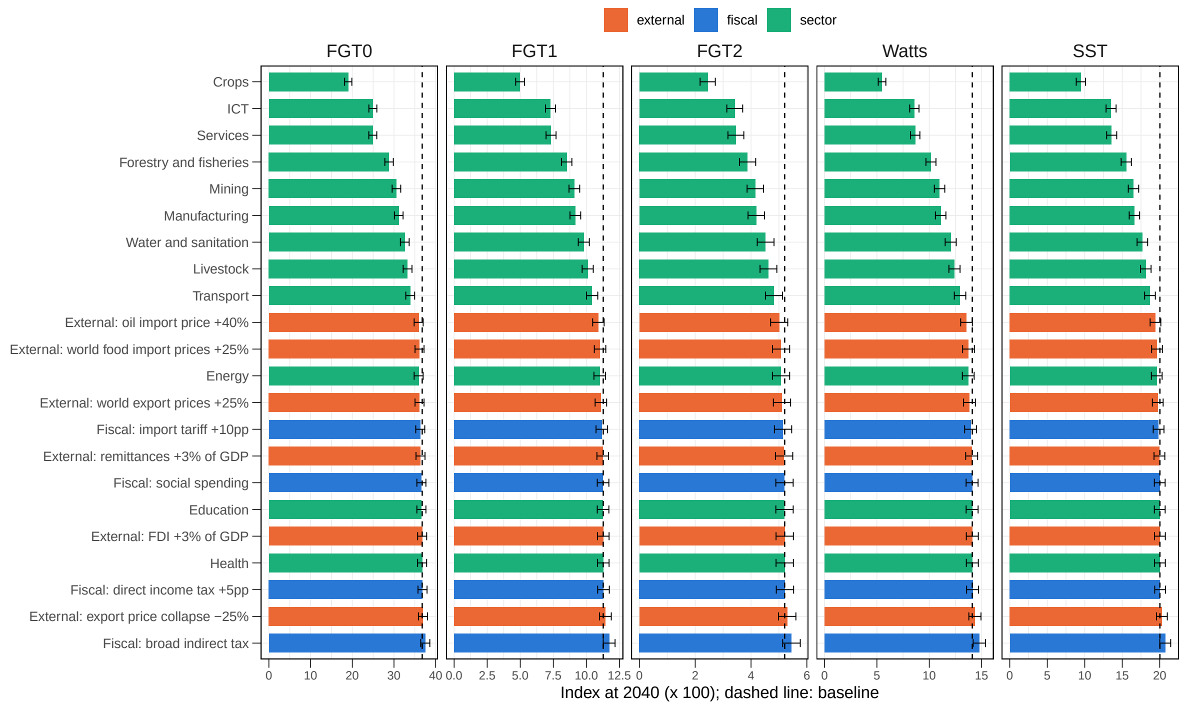

Figure 6.105: Poverty at the international line at 2040 by scenario: FGT_0, FGT_1, FGT_2, Watts and SST ($\times 100$) with 95 per cent confidence intervals. Dashed line: baseline.

6.7.9 Inequality

The baseline Gini at 2040 is 0.427. 6 of the 22 packages lower it and the rest raise it. The most equalising is **Crops** (0.388) and the most disequalising **Services** (0.452). Figure 6.106 shows the Gini beside eight other indices — the coefficient of variation, three Atkinson indices, three generalised entropy indices and the Duclos–Esteban–Ray polarisation index — each with its confidence interval and the baseline as a dashed line. The indices that weight the bottom of the distribution most heavily (Atkinson at $\varepsilon = 2$, entropy at $\theta = 0$) separate the packages most sharply, which is consistent with the packages differing mainly in what they do at the bottom of the distribution rather than at the top.

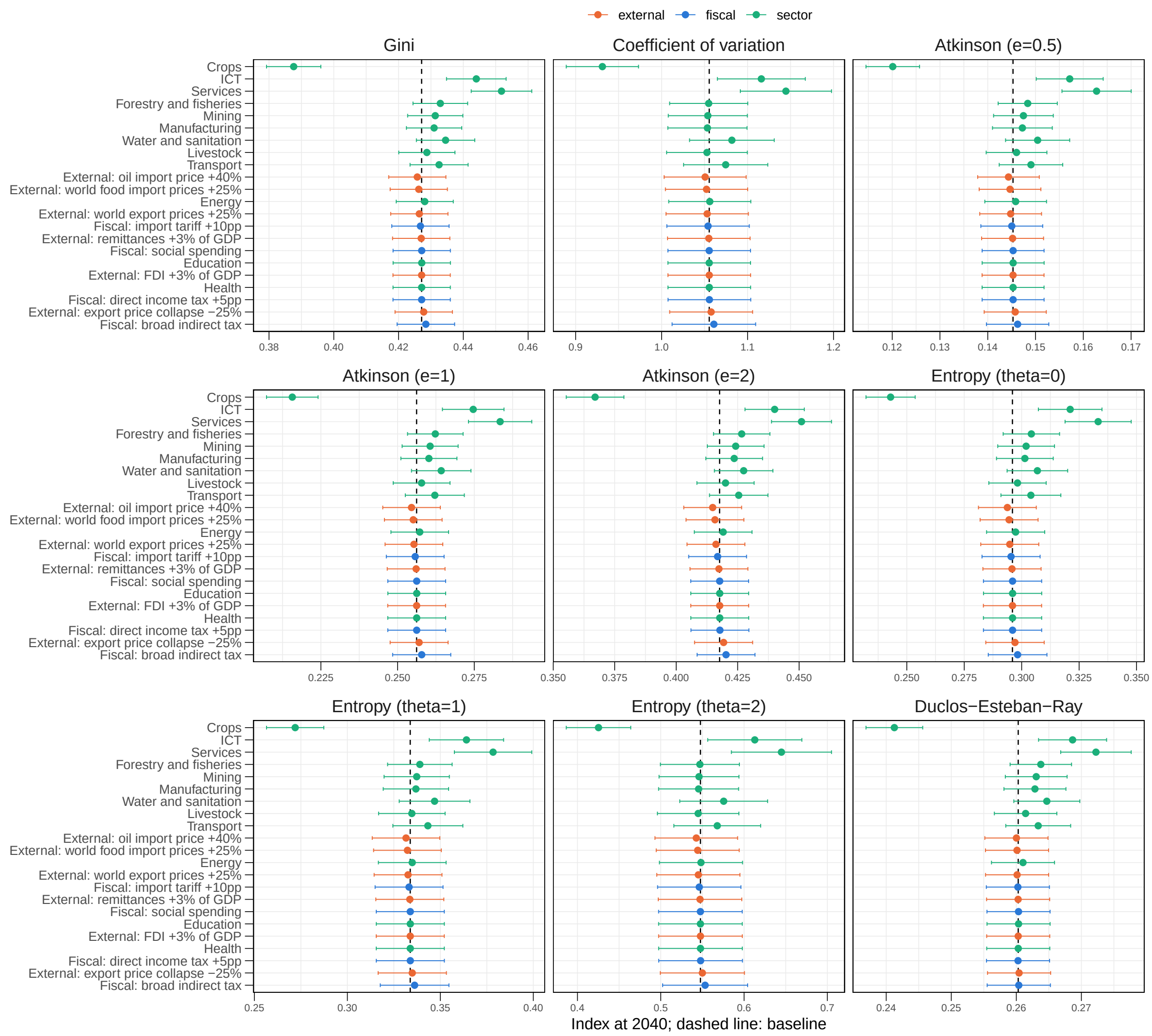

Figure 6.106: Inequality and polarisation indices at 2040 by scenario, with 95 per cent confidence intervals. Dashed line: baseline.

6.7.10 Quintile shares

In the baseline the poorest fifth holds 5.9 per cent of welfare and the richest fifth 49.5 per cent. Figure 6.107 charts the change in each quintile's share under every package. The bottom share rises most under **Crops** (+0.7 points) and falls most under **Services** (-0.4 points). A share is a zero-sum quantity, so the five panels should be read together: under Crops the top quintile's share moves by -3.5 points, which is where the bottom quintile's gain comes from.

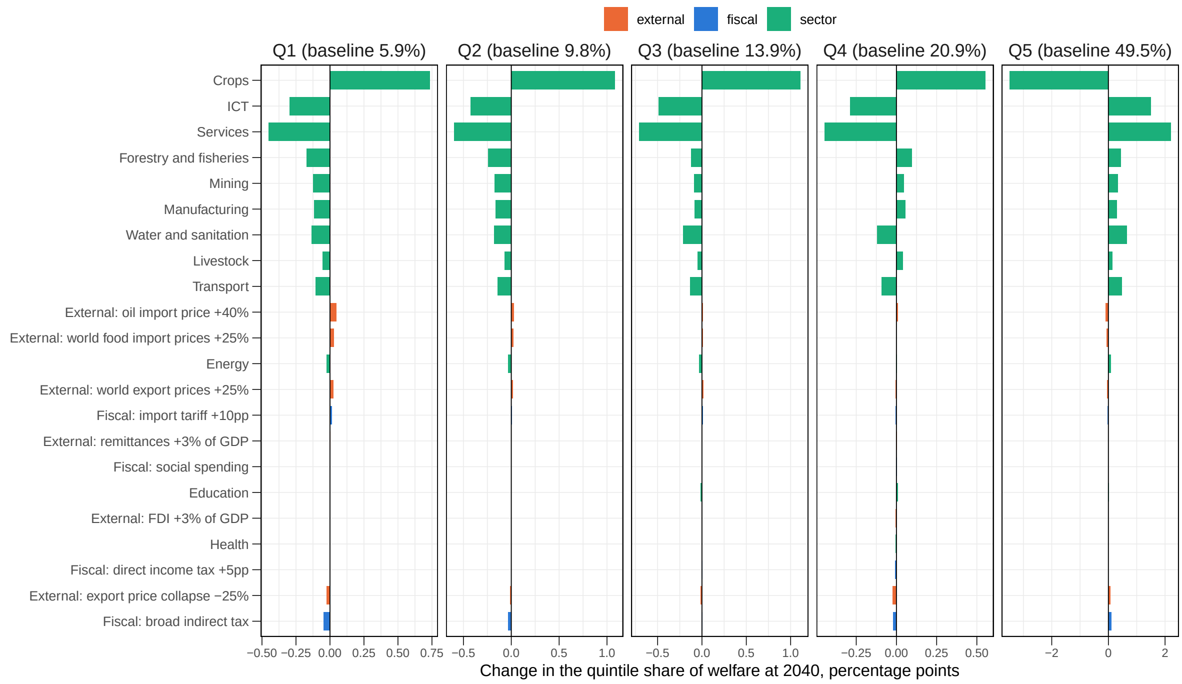

Figure 6.107: Change in each quintile's share of welfare at 2040 against baseline, percentage points, by scenario. Baseline shares in the panel titles.

6.7.11 Paired differences from baseline

Every index above is an estimate with a standard error, and a difference between two estimates is itself estimated. DASP's paired test treats the baseline and policy distributions as two observations of the same households, which is what they are here, and reports the difference with its standard error. Figure 6.108 charts that difference for the three FGT indices at both lines with a 95 per cent interval, and colours grey any difference that cannot be distinguished from zero. At the national headcount 20 of the 22 packages move poverty significantly; the exceptions are Health, External: FDI +3% of GDP — the packages the lever chapters already found to be reallocations rather than gains. A bar that is visible but grey is a reminder that a small simulated change in a headcount can be sampling noise in a 3,100-household panel.

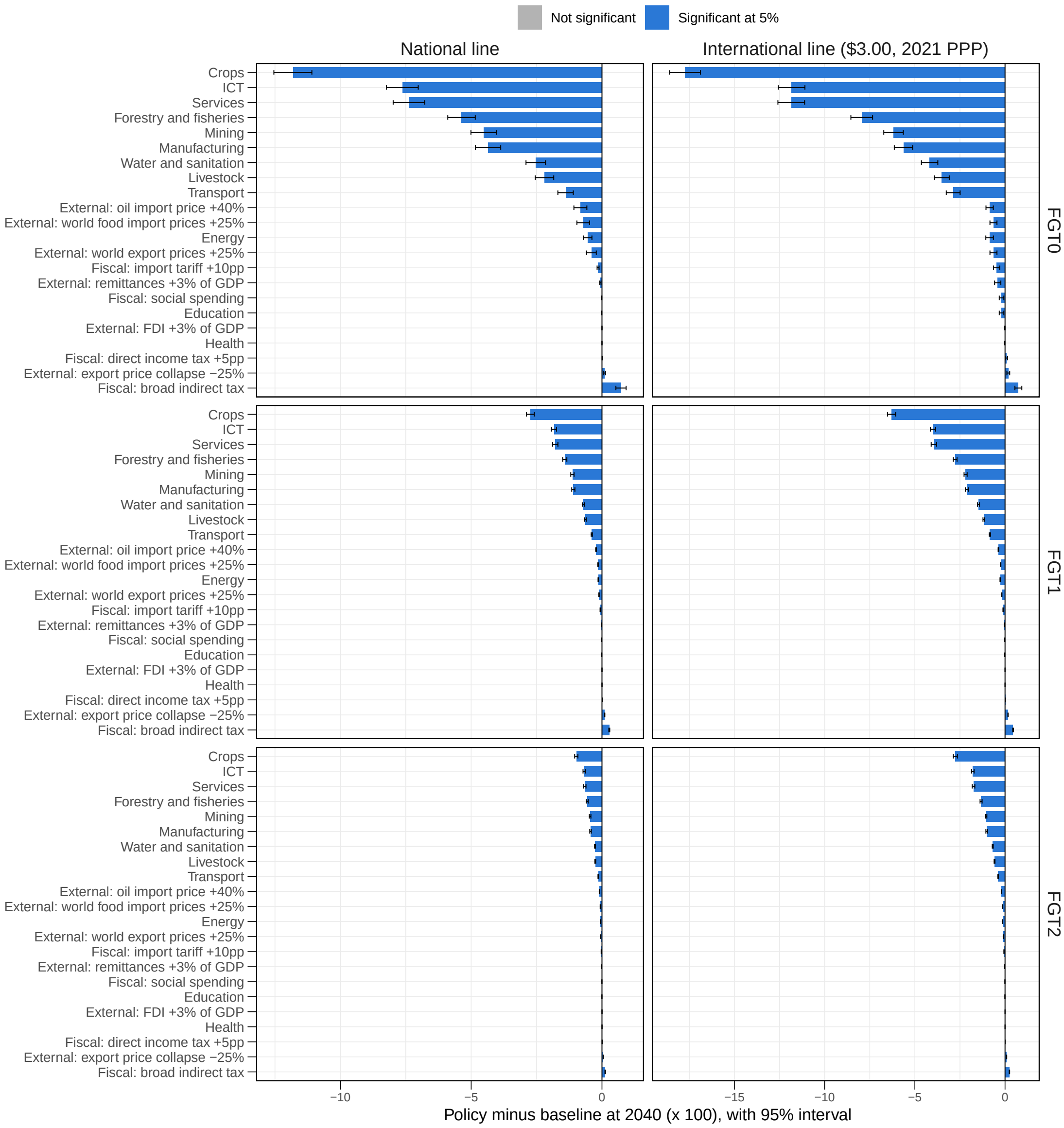

Figure 6.108: Paired differences from baseline at 2040 (policy minus baseline, ×100) for FGT_0, FGT_1 and FGT_2 at the national and international lines, with 95 per cent intervals. Grey: not significant at 5 per cent.

6.7.12 Pro-poor growth indices

Figure 6.109 charts the pro-poor growth indices for every package, each against the threshold that defines pro-poor on its own definition. The Kakwani–Pernia index is the ratio of the poverty reduction achieved to the reduction the same growth would have achieved had it been distributionally neutral; above one, the poor gained more than proportionately. 6 of the 22 packages with positive mean growth clear that bar. The highest among them is **External: remittances +3% of GDP** (1.75) and the lowest **Health** (0.00). Where mean welfare fell the ratio inverts its meaning — Fiscal: broad indirect tax (3.21) scores above one because both the poverty change and the growth rate are negative, so the poor lost more than proportionately — and the chart should be read against the growth panel beside it. The poverty-equivalent growth rate restates the same comparison in growth units: the rate of distributionally neutral growth that would have produced the observed poverty change. Where it exceeds the mean growth rate g the package was pro-poor in the sense of Kakwani and Son, and the fourth panel plots that excess directly.

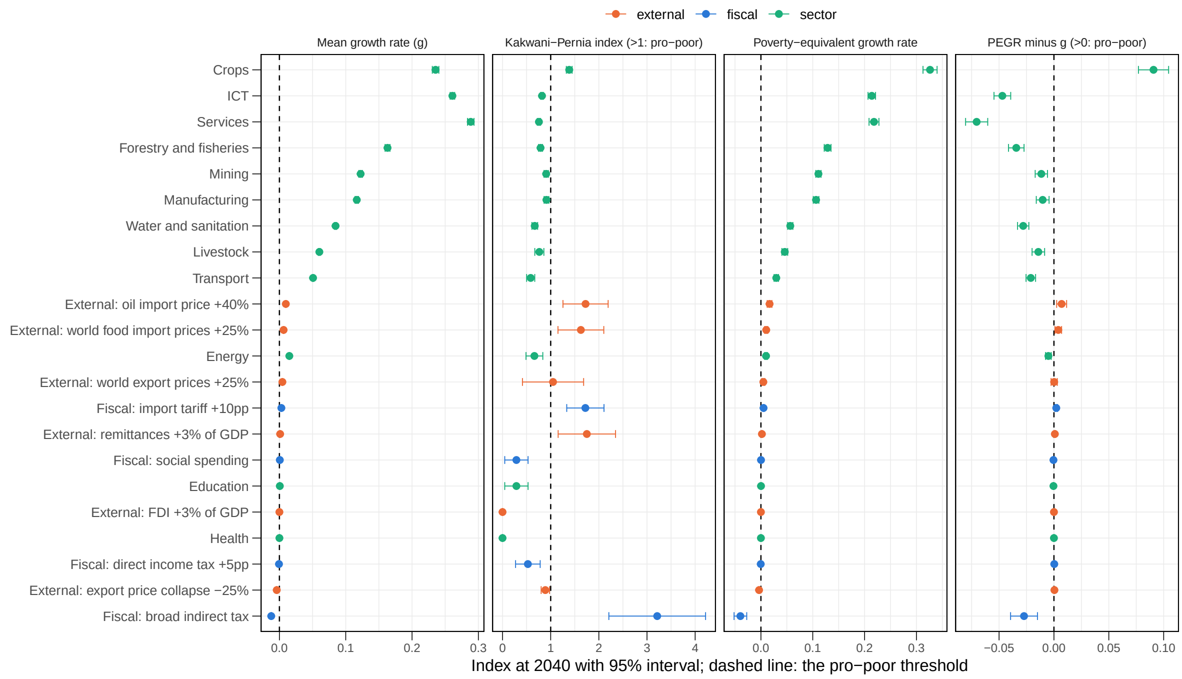

Figure 6.109: Pro-poor growth indices at 2040 by scenario, with 95 per cent intervals: the mean growth rate of welfare, the Kakwani–Pernia index (threshold 1), the poverty-equivalent growth rate and its excess over the mean growth rate (threshold 0).

6.7.13 Dominance tests

Figure 6.110 sets out the three DASP dominance tests as a verdict grid, one row per package. Green means the policy distribution dominates the baseline over the whole range of poverty lines (or, for Lorenz, is unambiguously more equal); red the reverse; grey a crossing, where the verdict depends on the line. At first order 11 packages dominate the baseline, 9 cross and 2 are dominated. Second order, which restricts attention to distribution-sensitive indices, resolves 4 of the crossings in the policy's favour, so 15 packages dominate at second order. The Lorenz column is the sterner test: only 5 packages are unambiguously more equal than the baseline, 7 are less equal and 10 cross. The packages that pass both the first-order poverty test and the Lorenz test — Crops, External: world food import prices +25%, External: oil import price +40%, External: world export prices +25% — are the ones for which 'less poverty and less inequality' holds for any line and any index.

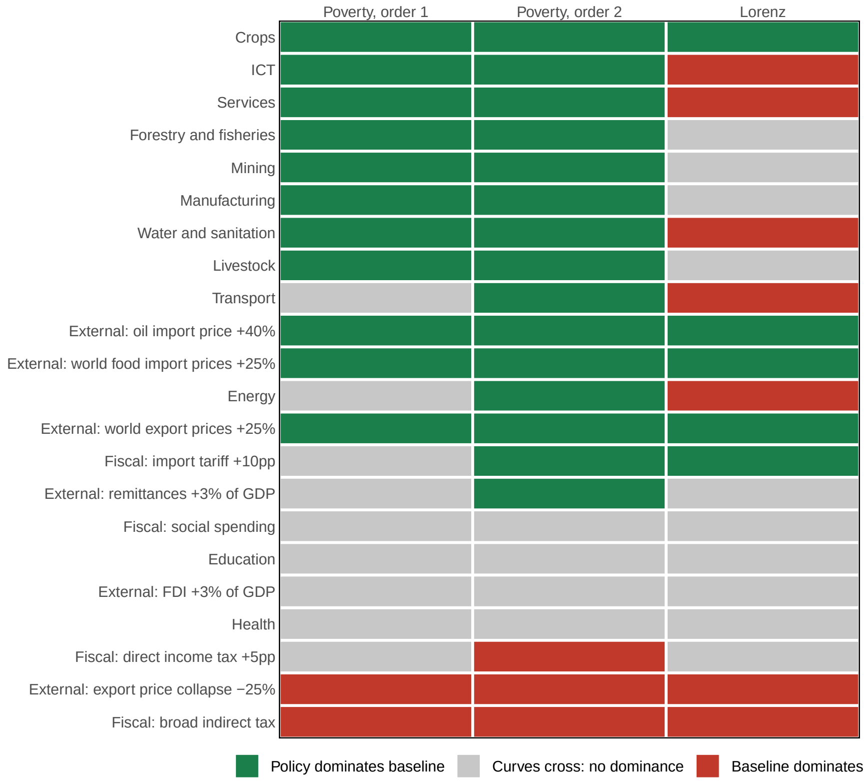

Figure 6.110: DASP dominance tests at 2040, policy against baseline: first- and second-order poverty dominance and Lorenz dominance. Green: policy dominates; red: baseline dominates; grey: curves cross.

6.8 Where the gains land: a spatial reading

The distributional chapter reports poverty for Uganda as a whole. That figure is an average over a country whose regions start from very different places: in the simulated 2040 baseline the headcount is 28.5 per cent in the Northern region, 23.4 in the Eastern, 18.1 in the Western and 6.9 in the Central; 22.6 per cent rural against 7.4 urban. A national number hides which of those communities a policy reaches.

This chapter joins the microsimulation to the survey's own geography. Each simulated household carries its region, district and urban or rural location from the National Panel Survey, so the change in the headcount under every scenario can be read at each of those levels and mapped.

6.8.1 How the maps were built, and what they cannot show

The survey is a panel of about 3,100 households. That is ample at the level of four regions — each carries 3,500 to 4,500 persons — but thin at the level of 122 districts. Twenty-two districts hold fewer than thirty sampled persons, and one of them swings by a hundred points on a single scenario, which is a sample of a handful of people crossing the line, not a finding. Districts below thirty persons are therefore drawn in grey as *insufficient sample*, never as a colour. A further sixteen districts on the boundary file were not sampled at all and are grey for that reason.

Three survey spellings differ from the boundary file's and are matched explicitly: Namtumba to Namutumba, Palisa to Pallisa, Rukingiri to Rukungiri. The region and district maps use the OCHA common operational boundaries for Uganda, and every map shares one diverging scale centred on zero, so a panel can be read against another without re-reading its legend.

6.8.2 The baseline geography

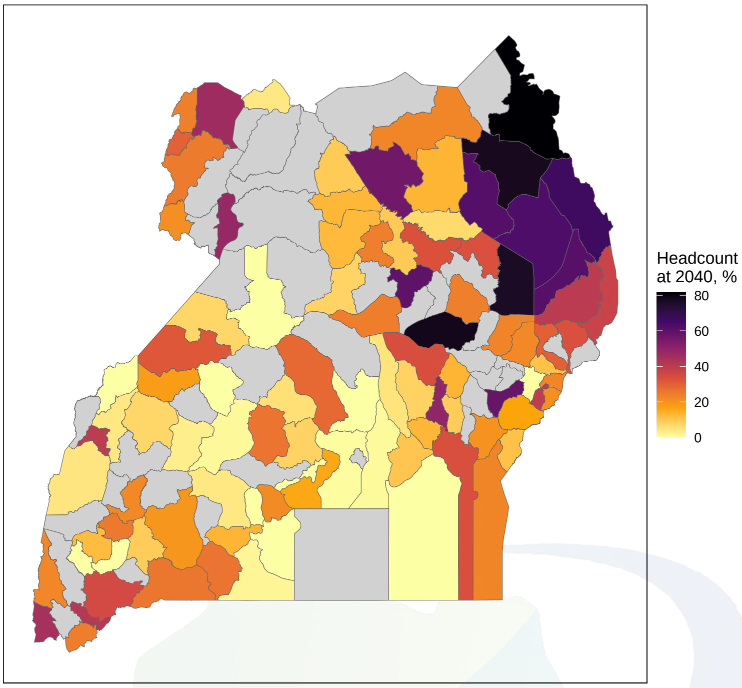

Figure 6.111: Poverty headcount at 2040 in the simulated baseline, by district. Grey districts are unsampled or below thirty persons.

Figure 6.111 is the reference the change maps should be read against. Poverty is concentrated in the north and east — Karamoja, Teso, Lango, Acholi, West Nile — and lowest in the Central region around Kampala. A scenario that removes ten points of poverty in a district starting at forty is doing something different from one that removes ten from a district starting at twelve, and a change map on its own does not distinguish them.

6.8.3 Every scenario, by region

The scenarios are mapped four to a page in a two-by-two grid, ordered by the population-weighted change in the national headcount so the strongest packages lead, over six pages. Every panel shares the one diverging scale printed beneath the grid.

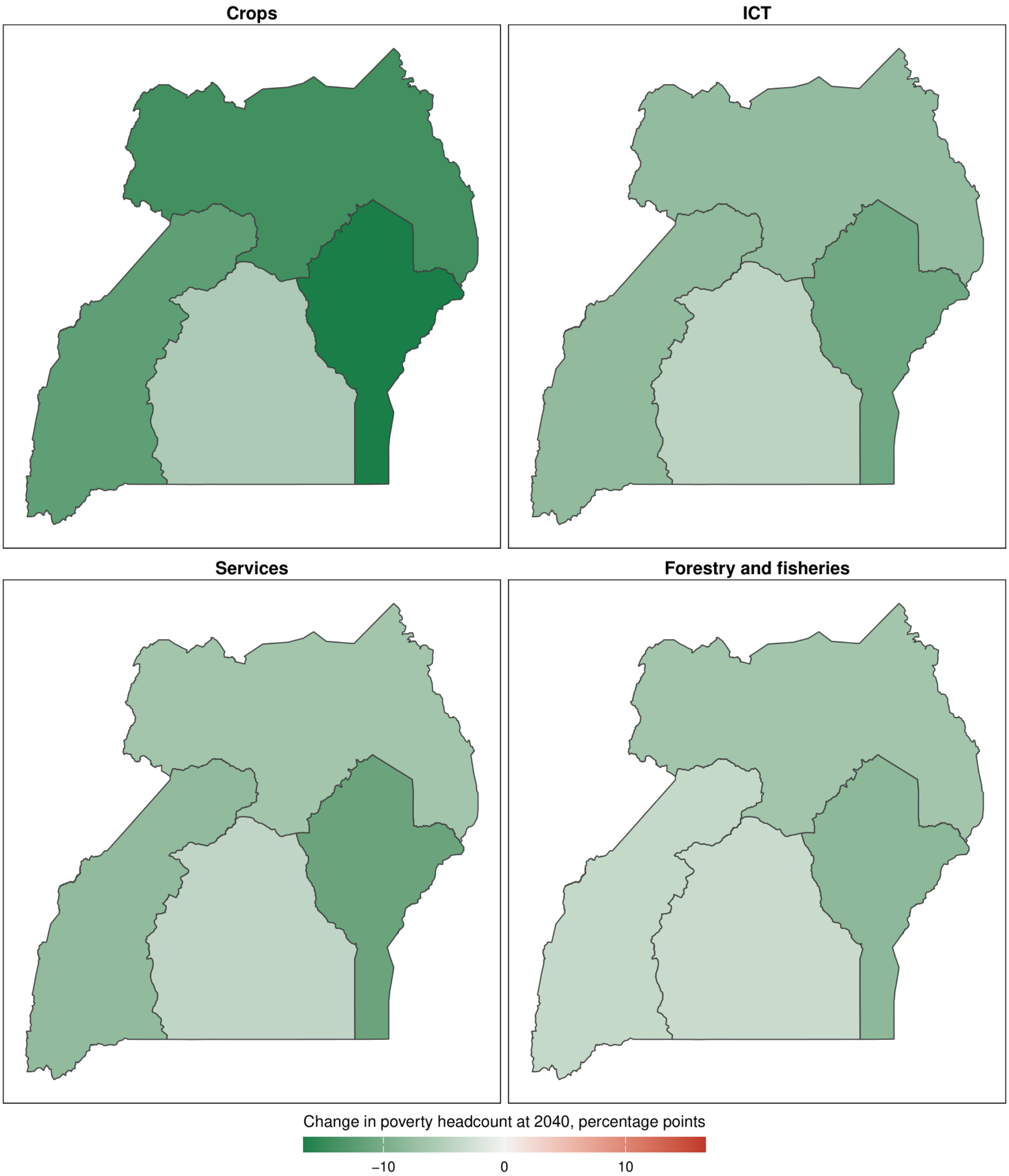

Figure 6.112: Change in the poverty headcount against baseline at 2040, by region (1 of 6): Crops, ICT, Services and Forestry and fisheries. Green is a fall in poverty; red a rise; every page shares the one scale.

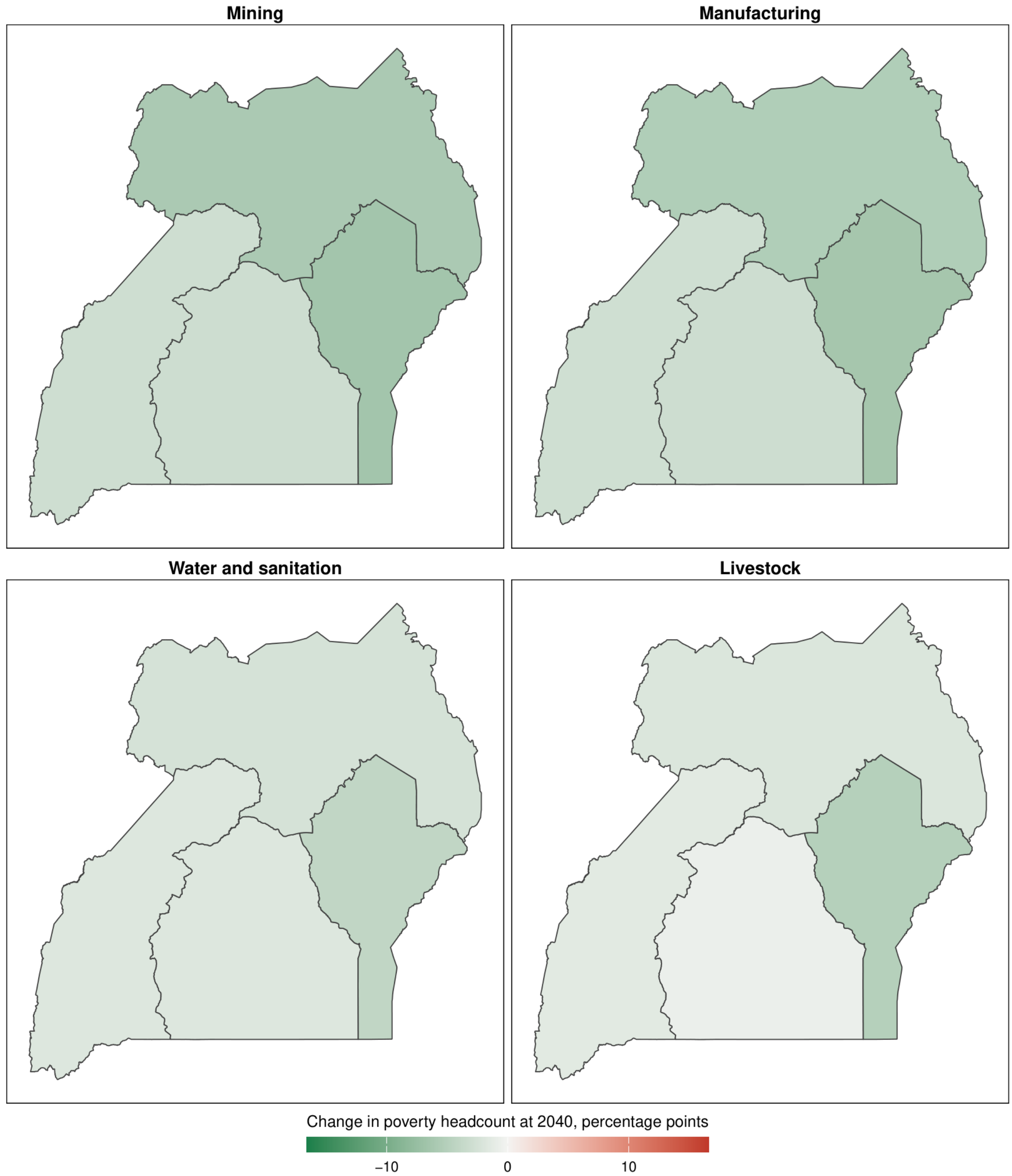

Figure 6.113: Change in the poverty headcount against baseline at 2040, by region (2 of 6): Mining, Manufacturing, Water and sanitation and Livestock.

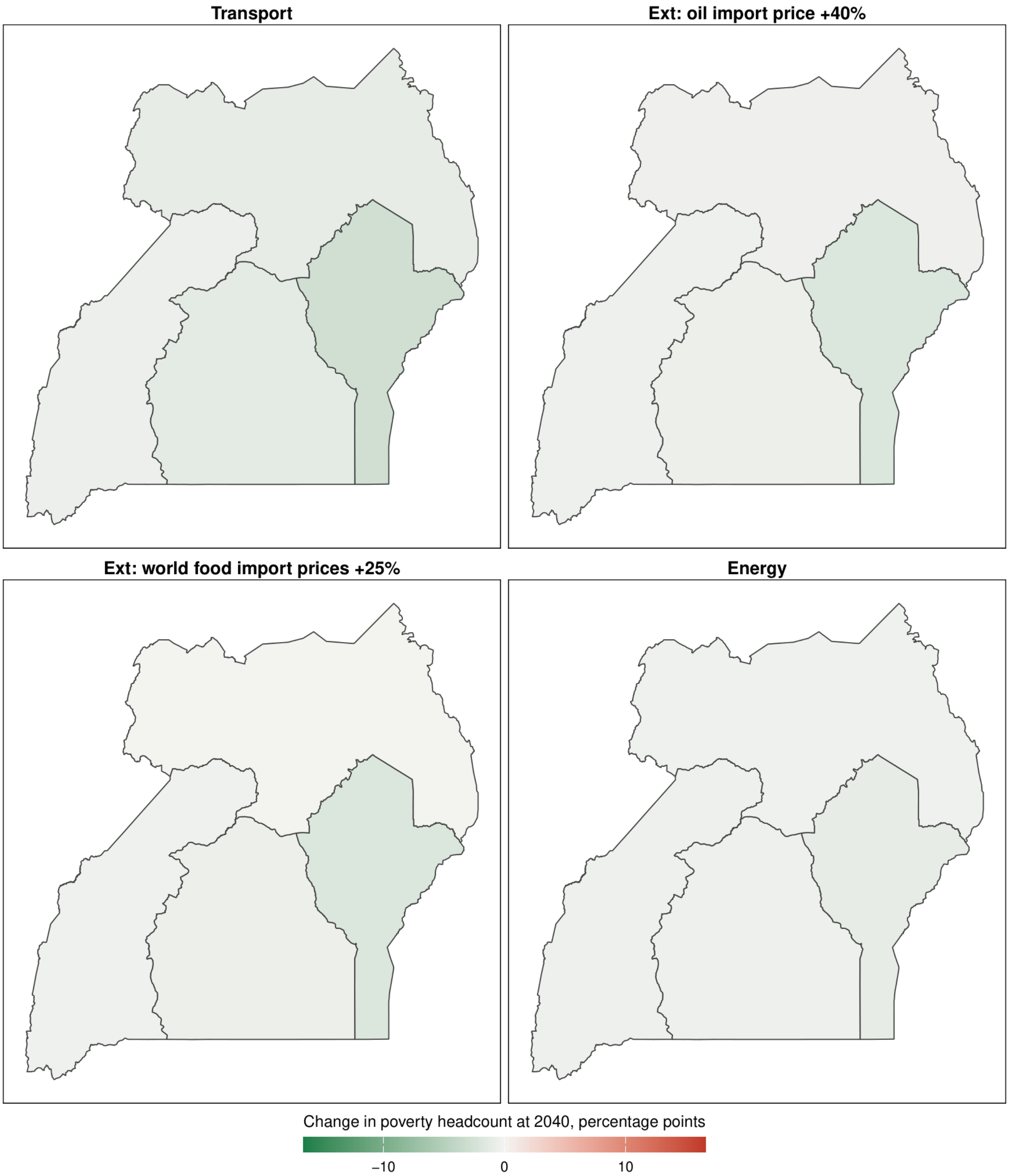

Figure 6.114: Change in the poverty headcount against baseline at 2040, by region (3 of 6): Transport, External: oil import price +40%, External: world food import prices +25% and Energy.

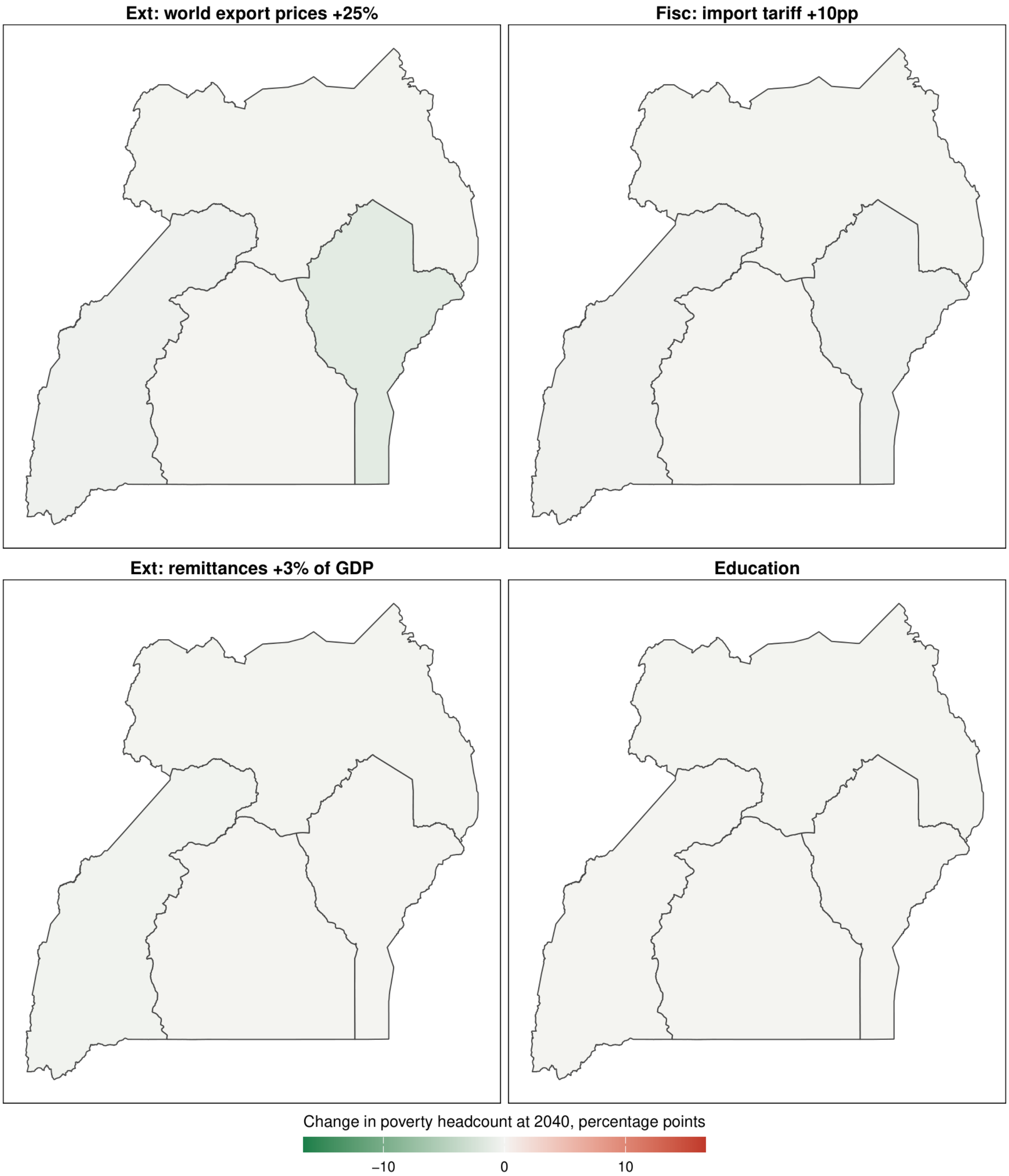

Figure 6.115: Change in the poverty headcount against baseline at 2040, by region (4 of 6): External: world export prices +25%, Fiscal: import tariff +10pp, External: remittances +3% of GDP and Education.

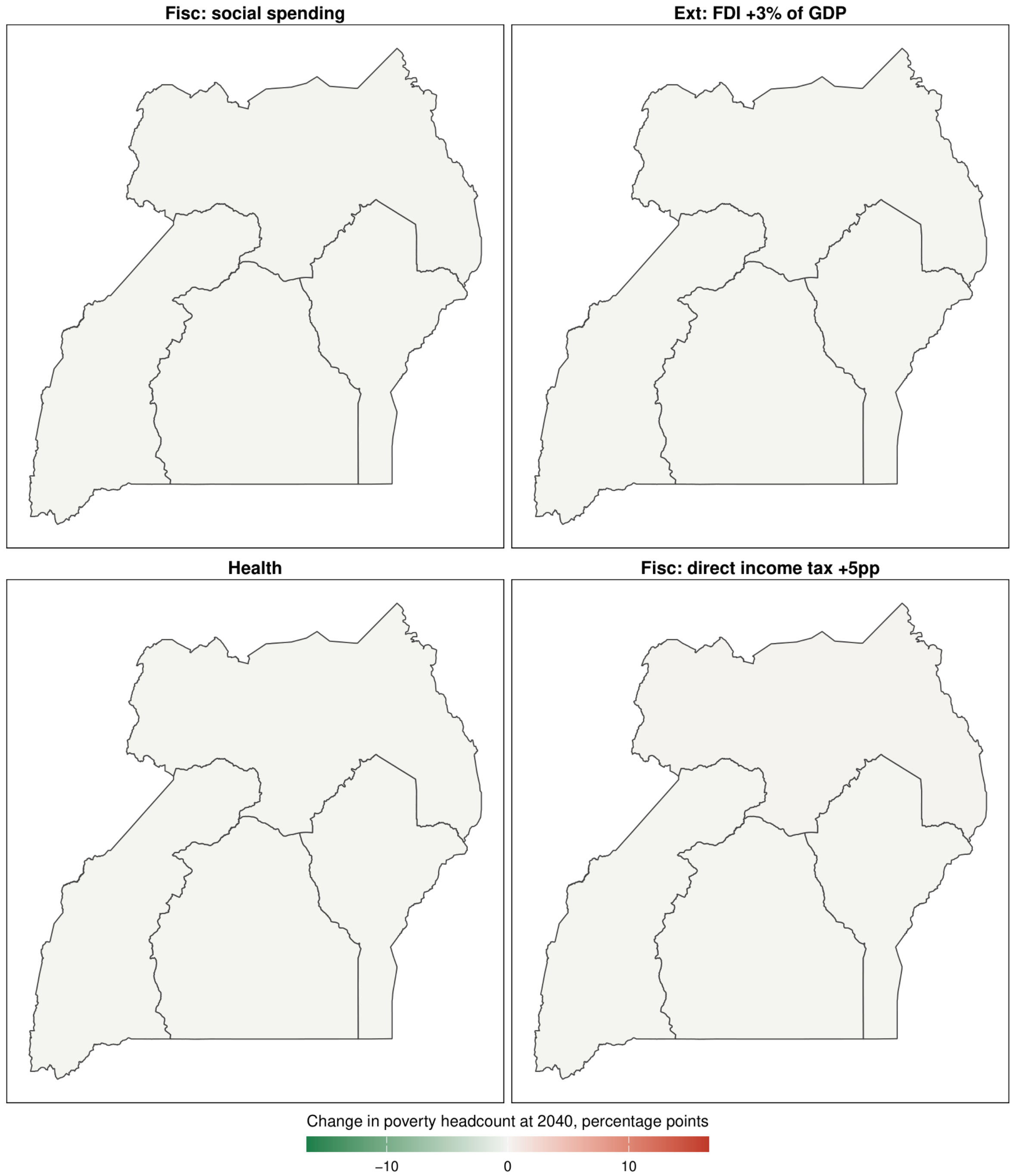

Figure 6.116: Change in the poverty headcount against baseline at 2040, by region (5 of 6): Fiscal: social spending, External: FDI +3% of GDP, Health and Fiscal: direct income tax +5pp.

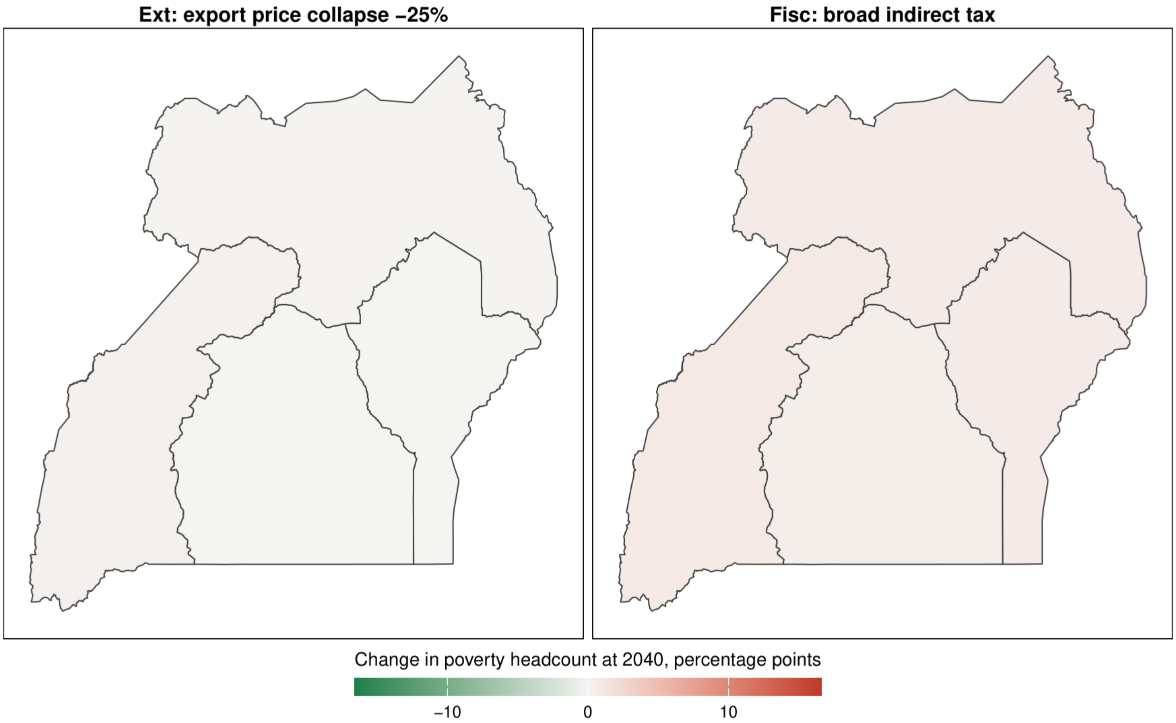

Figure 6.117: Change in the poverty headcount against baseline at 2040, by region (6 of 6): External: export price collapse -25% and Fiscal: broad indirect tax.

Figures effig:mapregion to effig:mapregion6 are the whole study, four scenarios to a frame. Two regularities run through it.

The Eastern region gains most from almost every productivity package. Under the crops package the Eastern headcount falls by 16.6 points, against 5.7 in the Central; under ICT, 10.8 against 4.4; under services, 11.2 against 4.2. The Eastern region is the best region for fifteen of the twenty-two scenarios.

The Central region gains least, and this is a floor rather than a failure. The Central region starts at 6.9 per cent. There is simply less poverty there to remove, so the same proportional gain in incomes moves fewer people across the line. A reader comparing the Central and Eastern bars on the crops package is not seeing a policy that favours the east; they are seeing a region that is already mostly above the line.

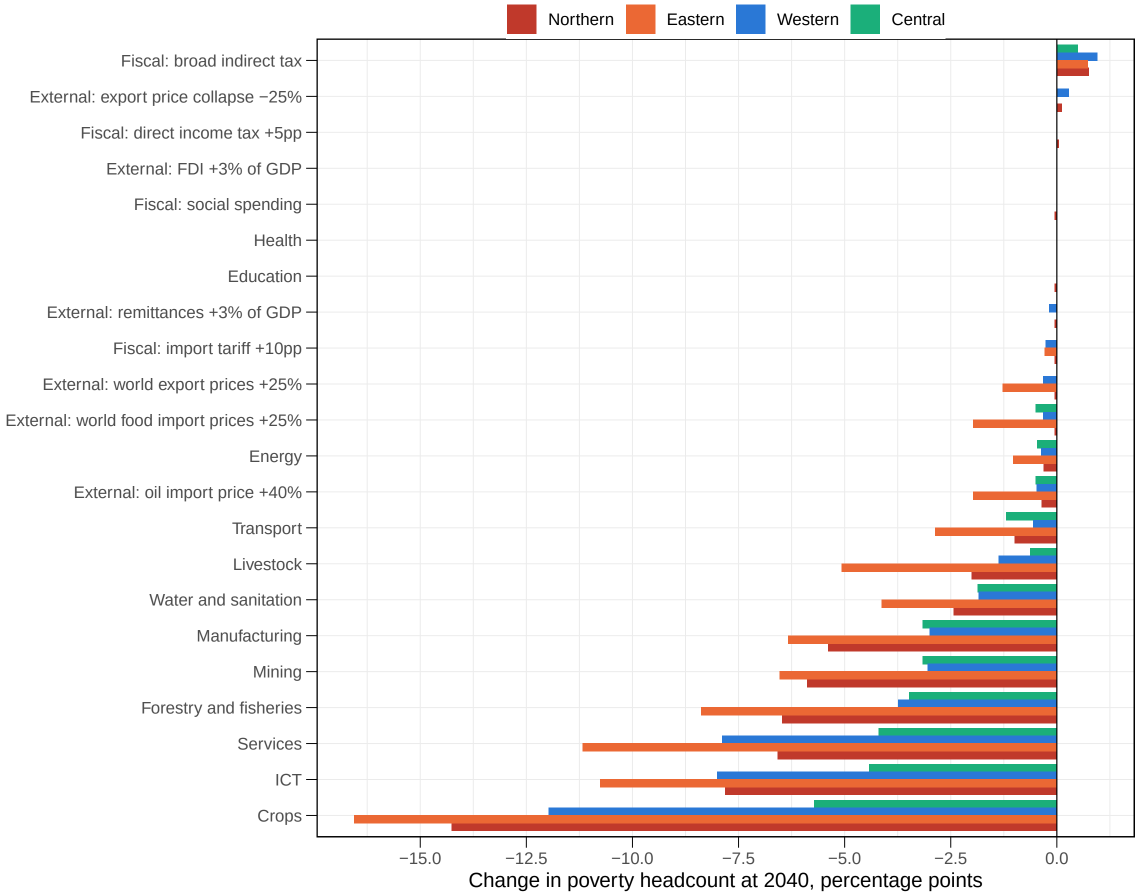

Figure 6.118: The same result as a chart: change in the headcount by region and scenario, ordered by the rural effect.

Figure 6.118 makes the magnitudes legible where the map makes the geography legible. The scenarios that raise poverty are visible at the top: the broad indirect tax raises the headcount in every region, worst in the Western (+0.95 points), and the export-price collapse raises it most in the Western too (+0.28) — which is where the coffee and tea belt sits, so a fall in the world price of what the west sells lands on the west.

6.8.4 Districts: every scenario

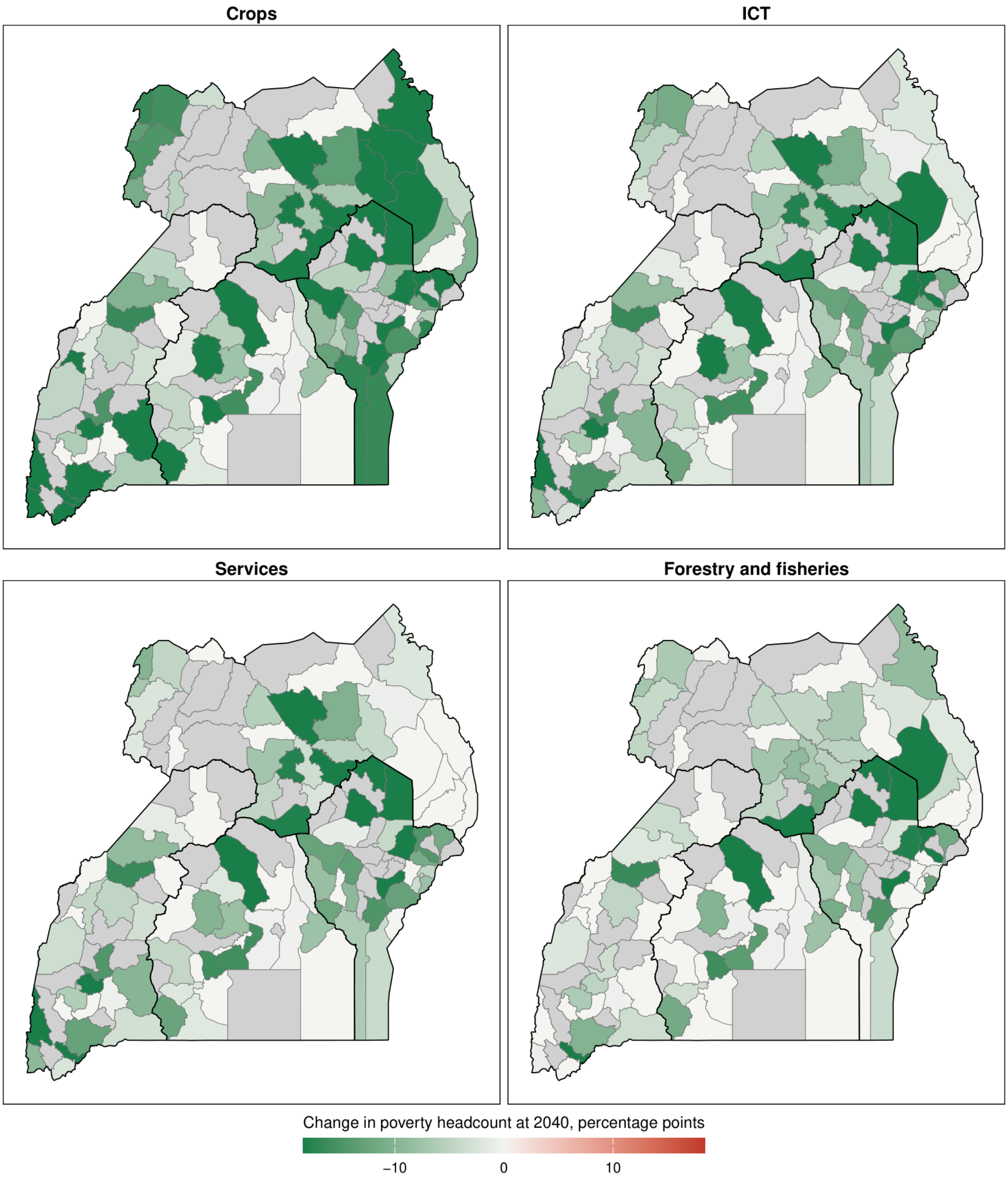

Figure 6.119: Change in the poverty headcount against baseline at 2040, by district (1 of 6): Crops, ICT, Services and Forestry and fisheries. Grey districts are unsampled or below thirty persons; black lines are the four regions. Green is a fall in poverty; red a rise; every page shares the one scale.

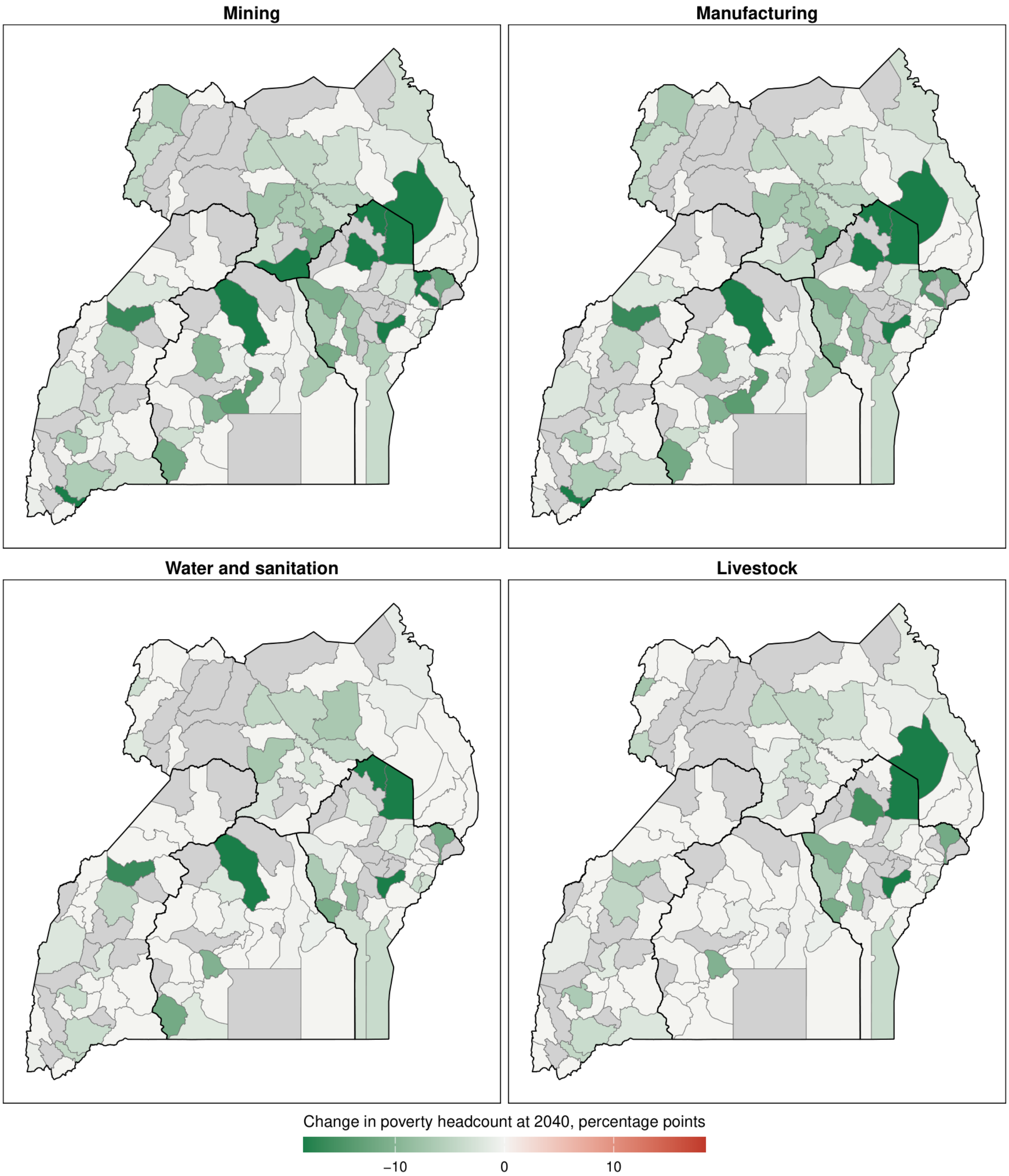

Figure 6.120: Change in the poverty headcount against baseline at 2040, by district (2 of 6): Mining, Manufacturing, Water and sanitation and Livestock. Grey districts are unsampled or below thirty persons; black lines are the four regions.

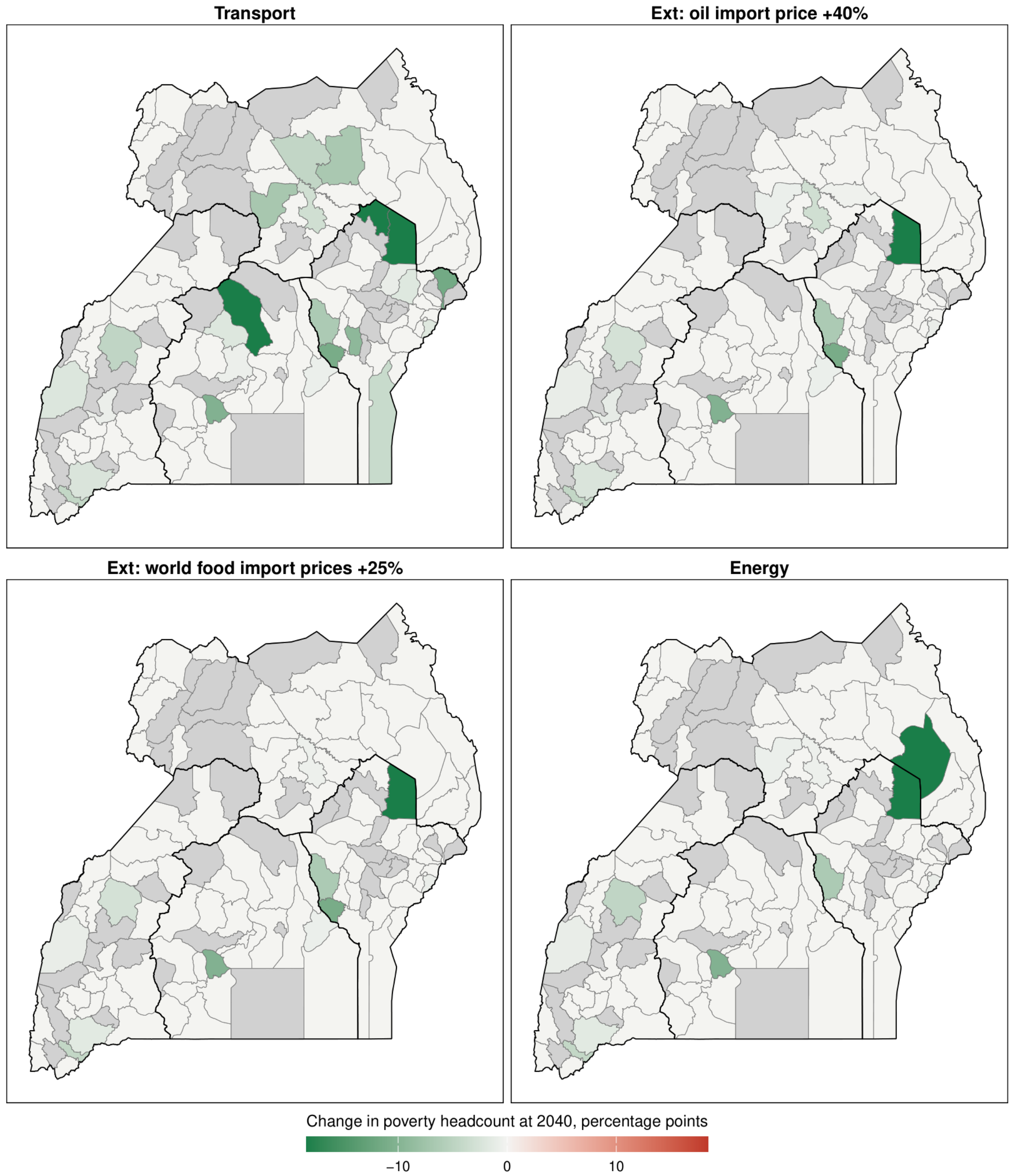

Figure 6.121: Change in the poverty headcount against baseline at 2040, by district (3 of 6): Transport, External: oil import price +40%, External: world food import prices +25% and Energy. Grey districts are unsampled or below thirty persons; black lines are the four regions.

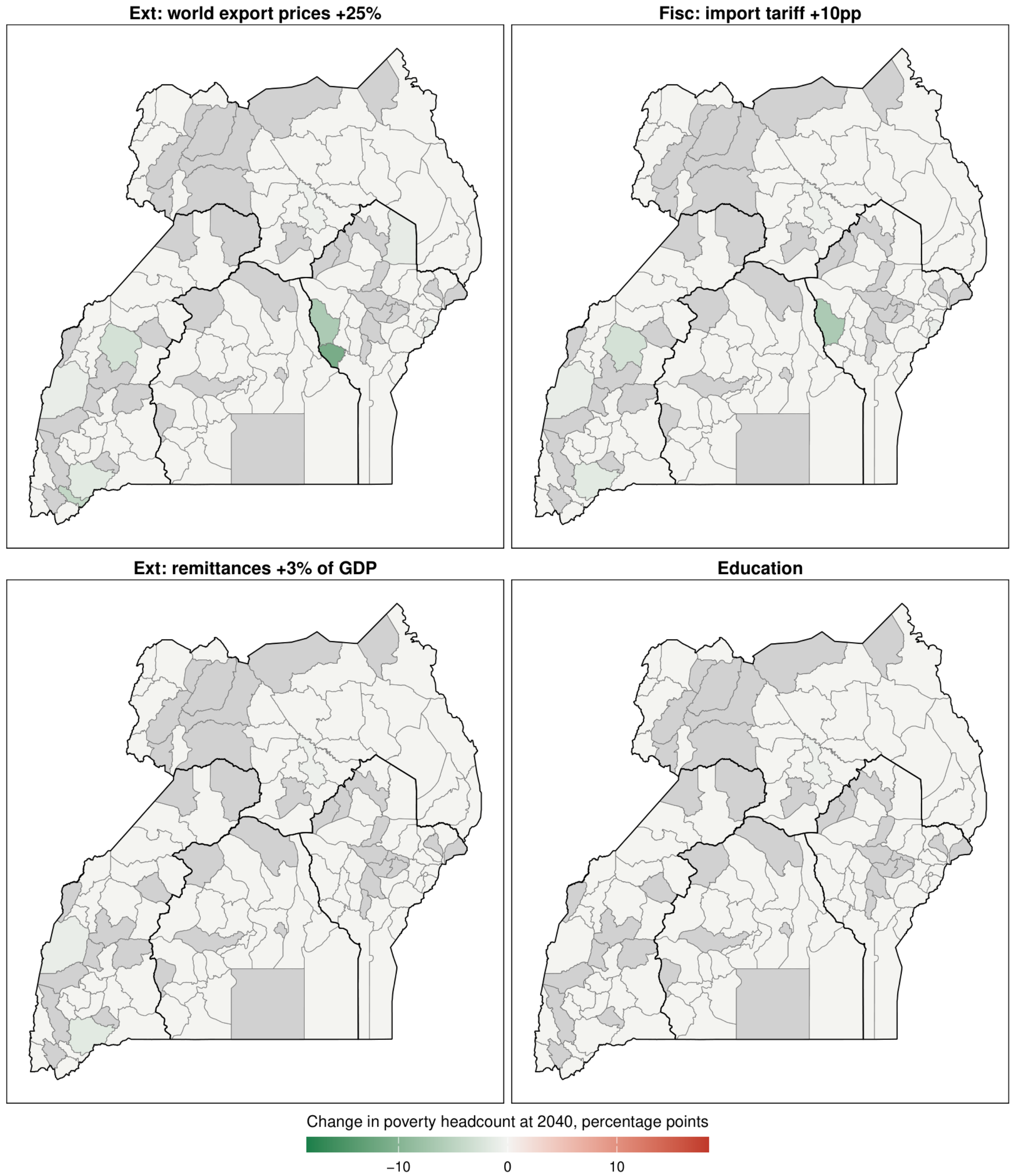

Figure 6.122: Change in the poverty headcount against baseline at 2040, by district (4 of 6): External: world export prices +25%, Fiscal: import tariff +10pp, External: remittances +3% of GDP and Education. Grey districts are unsampled or below thirty persons; black lines are the four regions.

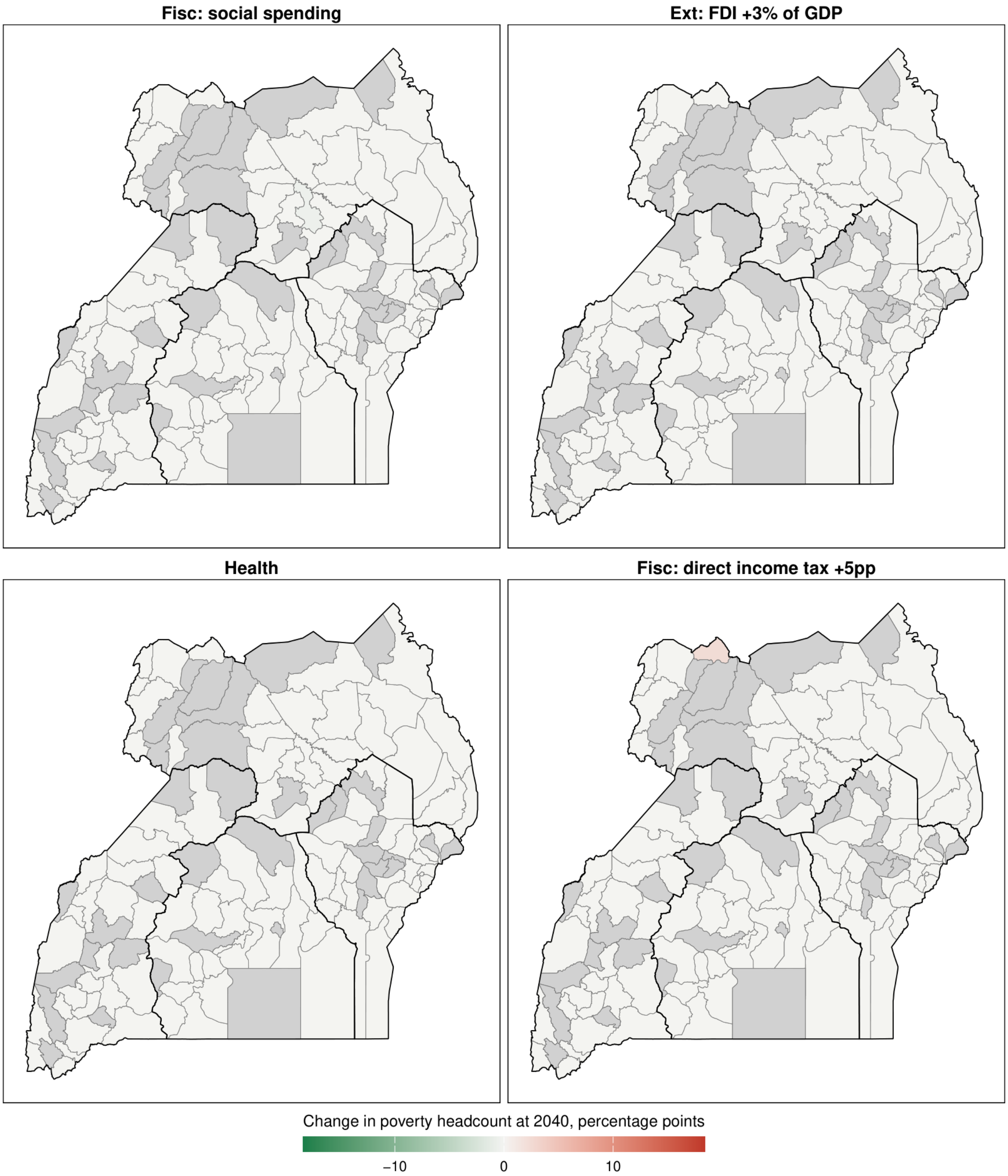

Figure 6.123: Change in the poverty headcount against baseline at 2040, by district (5 of 6): Fiscal: social spending, External: FDI +3% of GDP, Health and Fiscal: direct income tax +5pp. Grey districts are unsampled or below thirty persons; black lines are the four regions.

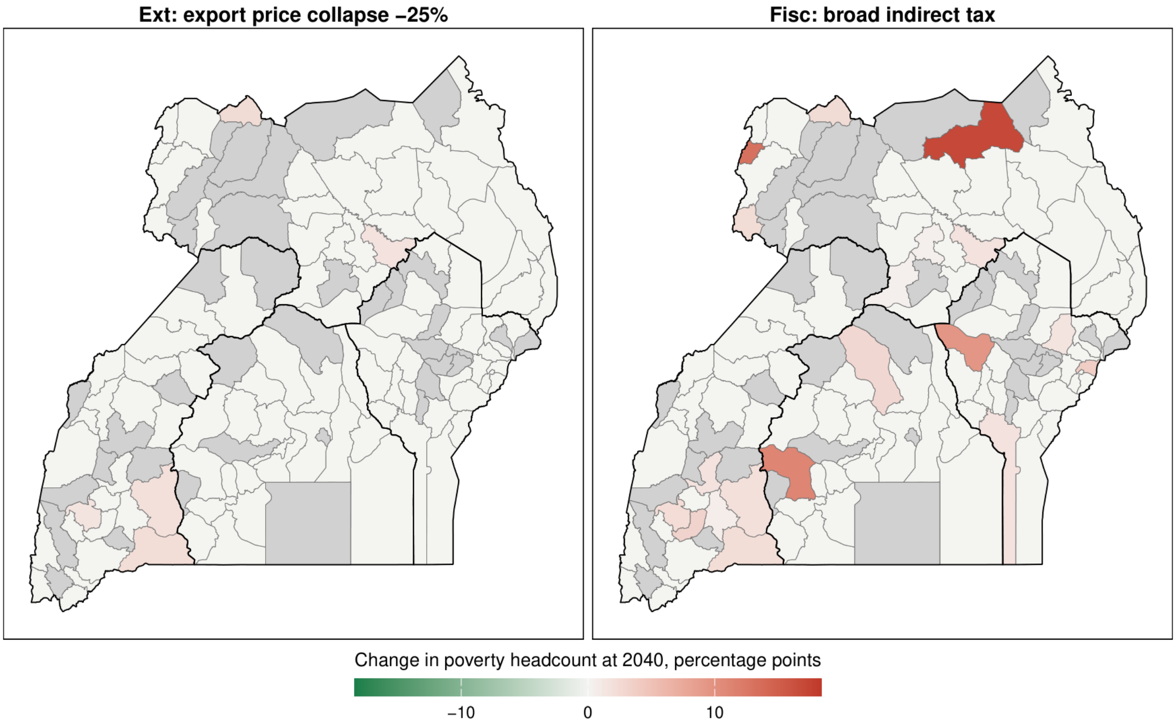

Figure 6.124: Change in the poverty headcount against baseline at 2040, by district (6 of 6): External: export price collapse -25% and Fiscal: broad indirect tax. Grey districts are unsampled or below thirty persons; black lines are the four regions.

Figures effig:mapdistrict to effig:mapdistrict6 take every scenario to district level, in the same order as the region maps. The crops package is the strongest and the most spatially concentrated: its largest gains sit in Karamoja and Teso in the north-east and in the south-west, the agricultural districts where a productivity gain in crops reaches the largest share of household income. ICT, services and manufacturing reach a wider set of districts each by less — their gains run through wages rather than farm income, and wages are earned more evenly across the map. From transport downwards the panels fade towards white: these are packages whose national effect is under one and a half points, and at district level that is a handful of households.

The last pages hold the scenarios that do harm or nearly nothing. The broad indirect tax is red almost everywhere it is coloured. The export-price collapse is faint red in the west and near white elsewhere. The food-import-price rise is faint green: it raises the price of what farmers sell, which helps the districts that sell food and does little for the rest.

6.8.5 Rural against urban

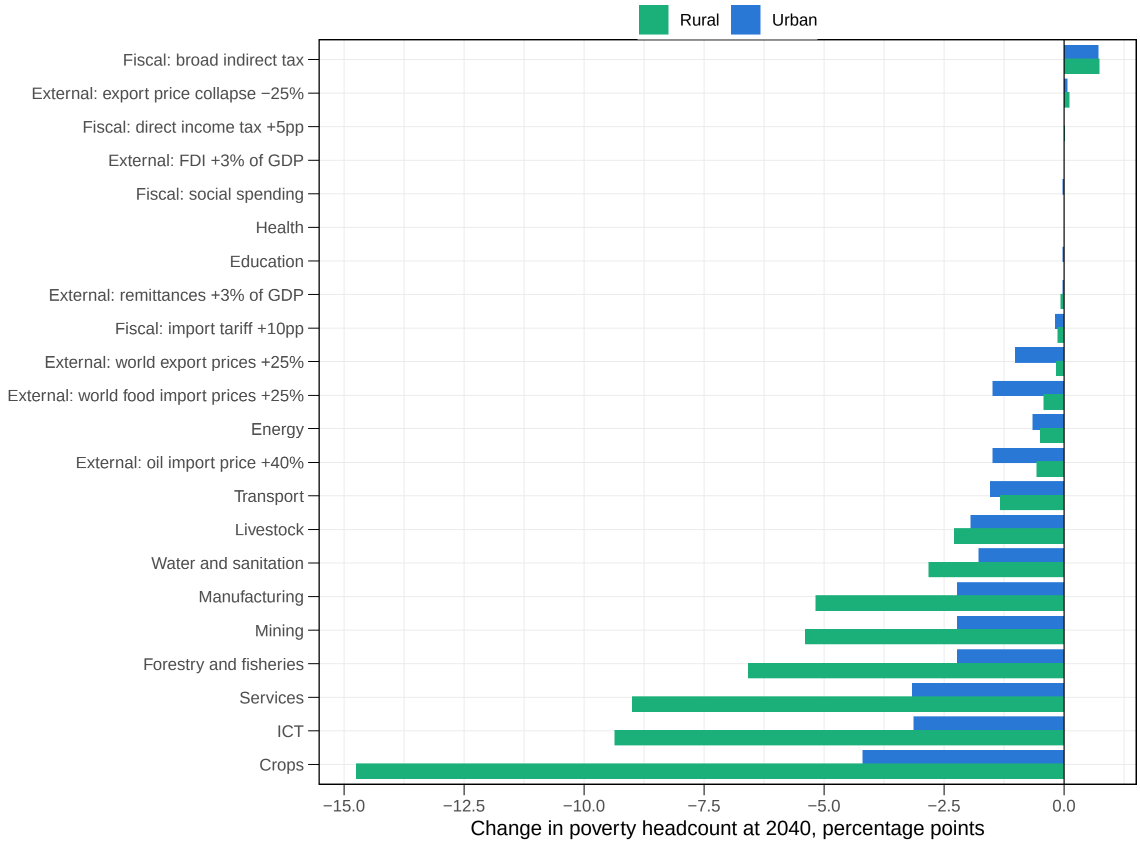

Figure 6.125: Change in the poverty headcount at 2040, rural against urban, every scenario.

Figure 6.125 is the cleanest single statement of incidence in the report. The crops package cuts rural poverty by 14.8 points and urban poverty by 4.2 — a rural gain three and a half times the urban one. ICT and services show the same shape at smaller scale, 9.4 against 3.1 and 9.0 against 3.2. These are packages whose gains reach the countryside.

Two scenarios reverse the pattern, and both are worth naming. The **oil import price rise** cuts urban poverty by 1.5 points and rural by only 0.6 — an import-substitution response whose employment gains are urban. The **transport package** does the same, 1.5 urban against 1.3 rural, which is what one would expect from a lever whose channel is logistics rather than farm output.

The scenarios with no rural effect at all — health, education spending, social spending, FDI, the direct income tax — are the ones the lever chapters already identified as inert or as pure reallocations. The map does not resurrect them.

6.8.6 What a spatial reading adds

The national headcount for the crops package falls by 9.2 points. That number is true and it is also an average of 16.6 in the east and 5.7 in the centre, of 14.8 in the countryside and 4.2 in towns. A programme designed on the national figure would misjudge both where to deliver it and what to expect from it. The maps here are drawn from the same simulated households as every other number in the report; they add no new assumption, only the geography the survey already carried and the national tables threw away.

They are subject to every limit stated for the distributional chapter, and to one more: a district estimate from a panel survey is noisy, and the grey cells are the honest acknowledgement of that. A district-level programme needs a district-level survey; these maps show where to look, not where to spend.

Chapter 7

Conclusion

CDCGE is a multi-region, recursive-dynamic computable general equilibrium model that brings the ENVISAGE 10.01 structure to the GTAP 11 database and implements it as a square mixed complementarity problem in Julia, solved with PATH. This report has documented the model in full: its background and design choices (Chapter 1); its complete equation system — sets, nested-CES production, an LES demand system with an energy nest, bilateral Armington/CET trade with a price-taking Rest-of-World anchor, a Y-block income and fiscal layer, market clearing and macro closure, an adjusted-CET land allocation with iso-elastic natural-resource supply, in-model emissions, a DICE-type climate module, and the recursive dynamics (Chapter 2); the MAMS-SDG human-development module that turns government spending by function into education, health, water, sanitation, energy-access and infrastructure outcomes and feeds them back into labour supply and productivity (Chapter 3); the calibration that recovers every benchmark parameter from a balanced SAM (Chapter 4); the operational pipeline from GTAP data to solved scenarios (Appendix A); and the full simulation study for Uganda (Chapter 6).

Several features distinguish CDCGE from a textbook CGE and merit emphasis. The *square-MCP-with-pinning* construction (Section 1.5) lets the model be assembled uniformly for any data configuration: empty nests, zero-supply factors and absent trade flows are pinned rather than special-cased, and the variable count always equals the equation count, so PATH can solve it. The *calibration-by-construction* property, with unit benchmark prices, makes the calibrated data an exact fixed point and gives the homogeneity test for free. The *energy-aware aggregation* — splitting electricity into fossil and clean generation and keeping the fuel sectors — is what lets a carbon price move the generation mix and the fuel mix, which is the mechanism behind every mitigation result. And the *price-taking RoW anchor* (Section 2.7) is what makes the bilateral trade system well-posed and robustly solvable under large shocks. Two further properties come from the layers built on that core. The human-development module is a *block-recursive tail on a square core* (Section 3.1): within a period it computes outcomes from the solved economy without disturbing it, and closes the MAMS two-way loop between periods, so development outcomes can be endogenised without putting the equilibrium solve at risk. And the EDIS layer's *base-year invariant* — every lever a ratio to the benchmark — is what makes a coupled satellite run reproduce the baseline exactly, makes the damped two-way iteration well-posed, and is asserted lever by lever in the bridge test suite.

The model also has deliberate limitations, documented throughout rather than hidden. It carries the five GTAP endowments (Land, unskilled and skilled labour, Capital, NatRes), with land allocated by an adjusted CET and natural resources on an iso-elastic supply curve; it has no capital vintages, no migration, no R&D/knowledge stock, no non-CO_2 gases, and a single LES demand system rather than the ENVISAGE menu of ELES/AIDADS/CDE; its emissions are in stylised intensity-based units rather than a measured inventory; and its base year is 2017 (the GTAP 11 reference year). There is no water-*allocation* module, because GTAP carries no water endowment to allocate — what the model does carry is water and sanitation *service delivery and access* (Chapter 3) and water supply as a sectoral productivity path from the water satellite. The human-development module inherits its own limitations from the data available: government spending is disaggregated by function but every function buys the same commodity basket, the education cohort chain is a base-normalised reduction of the MAMS grade-by-grade accounting, and the SDG logistic slopes are assumed rather than estimated unless calibrated to a country target. These are scope choices appropriate to a focused, transparent, solvable model; each is a candidate for future extension, and the modular Julia implementation makes such extensions tractable. As it stands, CDCGE is a complete, internally consistent, end-to-end working CGE: it loads real GTAP data, builds and balances a SAM, calibrates, and solves static, dynamic, policy and climate scenarios to optimality, with results that are economically interpretable and reproducible from the example drivers.

Appendix A

Using the model

This appendix is the operational guide. It walks through the full pipeline — loading the GTAP data, building the SAM, balancing it, aggregating it, calibrating, building and solving the static model, and running recursive-dynamic and policy simulations — with code snippets from the actual modules and example drivers. The model runs against a standard Julia environment with the packages `MAT`, `DataFrames`, `JuMP`, `PATHSolver`, `XLSX` and `Plots` installed. All paths below are relative to the `CDCGE/` project root.

A.1 Project layout

The repository is organised as follows:

```
CDCGE/
  Project.toml               # Julia dependencies
  data/                      # generated SAM workbooks (+ optional .mat copy)
  src/                       # the model
    GtapData.jl              # load the GTAP 11 value-flow headers (VDFB, EVFB, ...)
    GtapSAMBuilder.jl        # build the multi-region SAM from the GTAP data
    SectorConcordance.jl     # classify the 65 commodities (crop/energy/power/...)
    SAMBalance.jl            # RAS balancing + balance diagnostics
    SectorAggregation.jl     # 65 -> coarse/medium/fine group aggregation
    StaticCalibration.jl     # calibrate CES/LES shares + elasticities (Chapter 3)
    ModelContext.jl          # model context + blocks/*.jl: the square nested-CES MCP
    blocks/                  # ProductionBlock, SupplyBlock, IncomeBlock, ... (Chapter 2)
                             #   + FactorSupplyBlock  (land CET / NRS supply, 2.8.2)
                             #   + Infrastructure, EnergySpending, Water,
                             #     Sanitation, Health, Education (Chapter 3)
    HumanDevelopment.jl      # MAMS-SDG scaffolding: HDParams, logistics, feedbacks
    WorldBankData.jl         # WDI human-development panel -> HDParams (Africa)
    StaticSolve.jl           # build_static_model, PATH solve, scenarios, dynamics
    ClimateDICE.jl           # DICE carbon cycle + temperature + damage
    DataPaths.jl             # resolve the GTAP / EXIOBASE / EMERGING / WDI stores
    MacroIndicators.jl       # CPI, real wage, real exchange rate, real income
    Levers.jl                # the CGE injection points the satellite bridges write to
    BridgeIO.jl              # shared long-CSV interchange + concordance loading
    *Link.jl                 # Sector, Transport, Power, HumanDev, Household,
                             #   Trade, Macro, Fiscal, Climate bridges
    EDISRegistry.jl          # every EDIS satellite -> its adaptor and lever
    ExcelWriter.jl, EngineBridge.jl   # SAM -> Excel workbook utilities
    CDCGEData.jl             # umbrella module (re-exports the whole API)
    Results.jl, Plotting.jl           # solution extraction + figures
```

```
  bridge/                    # satellite interchange files + concordances
  examples/                  # run_static.jl, run_dynamic.jl, run_human_dev.jl,
                             #   run_edis_all.jl, ...
  test/                      # runtests.jl + test_bridges.jl (the lever invariants
      )
  results/                   # output workbooks + figures
  docs/                      # this report and the LaTeX documentation
```

The umbrella module `CDCGEData` includes all the submodules and re-exports the public API, so a driver script needs only one `include` and one `using`:

```
const ROOT = normpath(joinpath(@__DIR__, ".."))
include(joinpath(ROOT, "src", "CDCGEData.jl"))
using .CDCGEData
```

A.2 The PATH license

PATHSolver requires a license string, set once at the top of every driver:

```
import PATHSolver
PATHSolver.c_api_License_SetString(
    "1259252040&Courtesy&&&USR&GEN2035&5_1_2026&1000&PATH&GEN&31_12_2035&0_0_0
        &6000&0_0")
```

The solve helper `attach_path!` also sets this string and configures the solver options (convergence tolerance, iteration limits, a proximal-perturbation crash method, and the Fischer merit function) that make the stiff nested-CES Jacobian solve robustly.

A.3 Setting up the data

The first step loads the GTAP 11 value-flow headers into a typed container. The loader (`GtapData.jl`) reads the firm intermediate-demand headers (`VDFB`, `VMFB`), endowment payments (`EVFB`), the make matrix (`MAKB`), the final-demand headers (`VDPB`, `VDGB`, `VDIB` and their import counterparts), the bilateral trade headers (`VXSB`, `VCIF`, `VFOB`), and the macro headers (`SAVE`, `VDEP`, `VKB`, `POP`), exposing them through accessors:

```
db = load_gtap()                    # load the GTAP 11 database
```

The container `db` provides region and commodity indices and the raw headers. The sector concordance (`SectorConcordance.jl`) classifies the 65 commodities into structural classes (crops, livestock, coal, oil, gas, electricity-by-source, transmission/distribution, manufacturing, transport, services), which is what the aggregation step uses to build the energy-aware groupings.

A.4 SAM construction

`build_gtap_sam` reconstructs a balanced-by-intent multi-region SAM from the GTAP data. The build structure is one *focus* region plus an aggregated Rest-of-World; the focus region is named with the `focus` keyword:

```
blt = build_gtap_sam(db; focus="ken")
```

The Rest-of-World is built as a *full aggregated region* (its own `SEC`, `FAC`, `HH`, `GOV`, `INV` accounts), which is required for the multi-region trade block and the price-taking RoW anchor. Internally, for each region the builder: reconstructs firm intermediate use from `VDFB`/`VMFB` and writes one

`SEC:`r`:`i account per commodity; decomposes value added into the five GTAP endowments (Land, unskilled/skilled labour, Capital, NatRes) plus production and indirect taxes; splits final demand into `HH/GOV/INV` from `VDPB/VDGB/VDIB`; reads bilateral trade from `VXSB/VCIF/VFOB`; and closes each region's current account with foreign saving. All seven tax accounts (`PTAX, ITAX, MTAX, ETAX, VTAX, CTAX, DTAX`) are written, zero where the data record none. The result `blt.sam` is a long-format `DataFrame` with columns `row`, `col`, `value`.

A.5 Balancing the SAM

A SAM is balanced when each account's row total (receipts) equals its column total (outlays). The raw reconstructed SAM is close to balanced but not exactly so (rounding in the GTAP data, the value-added/tax decomposition, and one-sided accounts for a handful of commodities). `balance_sam` applies a midpoint-target RAS (bi-proportional / iterative proportional fitting) update:

```
bal = balance_sam(blt.sam)
assert_sam_balanced(bal)              # throws if any account is unbalanced
```

The algorithm forms the square matrix M from the long SAM, sets each account's *target* total to the midpoint of its current row and column totals, $t_k = \frac{1}{2}(\mathrm{row}_k + \mathrm{col}_k)$, and then iterates the classical RAS scaling:

```
for it in 1:max_iter
    rs = vec(sum(M; dims=2))                   # row sums
    for i in 1:n; (target[i]>0 && rs[i]>0) && (M[i,:] .*= target[i]/rs[i]); end
    cs = vec(sum(M; dims=1))                   # column sums
    for j in 1:n; (target[j]>0 && cs[j]>0) && (M[:,j] .*= target[j]/cs[j]); end
    rr = vec(sum(M; dims=2)); cc = vec(sum(M; dims=1))
    scale = max.(abs.(rr), abs.(cc), eps())
    worst_rel = maximum(abs.(rr .- cc) ./ scale)   # per-account relative gap
    worst_rel <= rtol && break
end
```

The convergence criterion is the maximum *relative* gap, $\max_k |\mathrm{row}_k - \mathrm{col}_k| / \max(|\mathrm{row}_k|, |\mathrm{col}_k|)$. The use of a *relative* tolerance is essential: SAM values span many orders of magnitude (millions of USD), and an absolute tolerance of, say, 10^{-9} would be unsatisfiable at that scale, whereas a relative tolerance of 10^{-10} converges in a few hundred iterations to machine precision. Accounts that are empty in both row and column but have a positive target are seeded with a tiny diagonal support value so the scaling can act on them.

A.6 Aggregation

For solving, the 65-commodity SAM is aggregated to one of the ENVISAGE groupings. The default medium 30-sector concordance is applied with:

```
agg = aggregate_gtap_sam(bal; concordance = gtap_med30_concordance())
```

`aggregate_gtap_sam` relabels each `SEC:`r`:`i account with its group code and sums the flows; the non-sector accounts (factors, final demand, taxes) are untouched, so the aggregated SAM remains balanced. The energy-aware coarse concordance maps the 65 commodities onto {AGR, LIVE, COAL, OIL, GAS, ELYFF, ELYCL, ETD, MANUF, TRANSP, SERV}, keeping the electricity split (fossil/clean) and the fuel sectors that the energy nests require; the medium (30-sector, default) and fine (63-sector) concordances are also available.

A.7 Calibration

Calibration turns the balanced, aggregated SAM into a `Calib` object holding every benchmark level and share (Chapter 4):

```
cal = calibrate_sam(agg; separate_land_natres=true)
```

The `Calib` struct exposes the regions, sectors and (five) factors, the benchmark levels ($\bar{X}, \bar{Z}, \bar{F}, \bar{VA}, N\bar{D}0, \bar{C}, \bar{G}, \bar{I}$ the shares ($\bar{s}^d, \bar{s}^m, \bar{s}^{cd}, \bar{s}^{ce}, \bar{s}^c, \bar{s}^g, \bar{s}^{inv}$), the tax rates ($\tau^p, \tau^i, \tau^d$), the savings rates $\overline{aps}$, the foreign balances $\bar{Sf}$, and the elasticity dictionary. The defaults are the values in Tables 2.2–2.4; to override an elasticity, pass a modified dictionary: `calibrate_sam(agg; elasticities=merge(ELAST_DEFAULTS, Dict("sigma_v"=>1.2)))`.

A.8 Building and solving the static model

The static MCP is built with `build_static_model` (in `StaticSolve.jl`, which assembles `ModelContext.jl` and the `blocks/*.jl` blocks — ProductionBlock, SupplyBlock, IncomeBlock, DemandBlock, TradeBlock, MarketsBlock, FactorsBlock, FactorSupplyBlock, ClosureBlock, EquilibriumBlock) and solved with PATH. The convenience wrapper `solve_cal` does both:

```
m = build_static_model(cal)           # assemble the square MCP
@info "size" variables=m.nvars equations=m.neqs square=(m.nvars == m.neqs)

m, status = solve_cal(cal)            # build + attach PATH + optimize
@info "solve" status                  # expect LOCALLY_SOLVED
```

`build_static_model` takes optional keyword arguments naming the energy commodities for the nests; the defaults match the coarse aggregation:

```
m = build_static_model(cal;
        numeraire_region = cal.regions[1],
        world_region     = "ROW",
        elec_fossil = ["ELYFF"], elec_clean = ["ELYCL"],
        coal = ["COAL"], oil = ["OIL"], gas = ["GAS"])
```

The returned `StaticCGE` holds the JuMP model (`m.jm`), the dimensions, and the variable/equation counts. A solved model is queried through the JuMP object or the tidy extractor `solution_df(m)`, which returns a `DataFrame(variable, base, index, value)`; for example, GDP at market prices by region is the rows with `base == "GDPMP"`. The full static driver is `examples/run_static.jl`:

```
db  = load_gtap()
blt = build_gtap_sam(db; focus="ken")
bal = balance_sam(blt.sam); assert_sam_balanced(bal)
agg = aggregate_gtap_sam(bal; concordance=gtap_med30_concordance())
cal = calibrate_sam(agg; separate_land_natres=true)
m, status = solve_cal(cal)              # build_static_model + attach PATH +
    optimize
@info "solve" status                    # expect LOCALLY_SOLVED
```

On a focus-plus-RoW coarse build this assembles a square system of 2,202 variables and equations and solves to `LOCALLY_SOLVED` in zero major iterations (the benchmark is an exact fixed point), with no NaN or Inf in the solution.

A.9 Dynamic simulations

The recursive-dynamic loop run_recursive solves the static equilibrium each period and grows the factor endowments for the next, stepping the climate state as it goes (Section 2.11). It returns a tidy long-format DataFrame(period, region, variable, value):

```
df = run_recursive(cal; nperiods = 10,
        deprec = 0.05, endogenous_capital = true,
        g_tfp  = 0.012,         # labour-augmenting productivity growth
        g_lu   = 0.01,          # unskilled labour-supply growth
        g_ls   = 0.015,         # skilled labour-supply growth
        aeei   = 0.01,          # autonomous energy-efficiency improvement
        climate = true,         # step the DICE module each period
        damage_feedback = false)
```

The recorded variables are, per period: YF_total and YH (factor and household income) and S_I (investment) by region; Ks and KSV (the in-model and tracked capital stock); and, for the pseudo-region GLOBAL, CO2, TATM, FORC, DAMAGE, TFP and a per-period status flag. The driver examples/run_dynamic.jl runs the 3-region, 10-period baseline and writes the result to an Excel workbook. The warm-start (homotopy) between periods is automatic: each period is solved from the previous period's solution, which is what makes the dynamic run robust under large carbon-tax shocks.

A.10 Scenario levers

Policy scenarios are constructed by transforming the calibration before solving. The helper functions return a modified copy of the Calib, leaving the benchmark intact:

- **Carbon price.** with_carbon_tax(cal, price) adds an ad-valorem-equivalent surcharge to the indirect-tax rate of each fossil-energy commodity, computed from the CO_2 intensity: the rate increment is price $\times\ \rho_i/10^6$. A price of \$50/tCO_2 thus raises the indirect-tax rate on coal by $50 \times 2200/10^6 = 0.11$, on fossil power by 0.125, and so on. This is the channel by which a carbon price reaches the energy nests (P-10)–(P-13) and (D-4)–(D-7).

- **Income-tax recycling.** with_income_tax(cal, kappa_h) sets the household income-tax rate κ^h, which appears in (Y-7) and (Y-11) — used to recycle carbon revenue.

- **Factor growth.** grow_factors(cal; gK, gL) and grow_capital(cal, m) scale factor endowments (the latter using the solved investment for endogenous accumulation), as used inside the dynamic loop.

- **Country-only carbon wedge (CBAM/leakage).** The native carbon price is applied uniformly across regions. For the border-adjustment and leakage analysis a thin helper of the form with_carbon_tax_<iso>(cal, price) adds the price to the fossil indirect-tax rates of *one* region only — editing tax_i[(iso, s)] for the fossil commodities s — leaving the rest of the world untaxed. Comparing a country-only wedge with the same price applied uniformly isolates carbon leakage (the rest-of-world emission response) and the competitiveness/trade-balance effect that a border carbon adjustment is designed to offset (Section 7.6 of the country reports).

- **Clean-electricity (renewable-subsidy) lever.** A renewable subsidy is represented as a productivity boost to clean electricity, supplied through the same prod dictionary as a multiplier > 1 on ELYCL (e.g. prod = Dict((iso, "ELYCL") $\Rightarrow$ 1.15)), which lowers its effective cost and displaces fossil generation.

- **Multi-channel adaptation.** The keywords `adaptation`, `dam_ag/dam_wat/dam_cap/dam_lab`, `phi_auto`, `phi_plan` and `adapt_cost_share` activate and parameterise the channel damage–adaptation extension of Section 2.11.6; a net-zero pathway is a rising `carbon_price` vector, and a cap is solved with `solve_emission_cap` (Section A.11).

```
m50, st = solve_cal(with_carbon_tax(cal, 50.0))      # one-shot $50/tCO2 solve
co2, byr = co2_emissions(m50)                        # read in-model emissions
```

A.11 Carbon sweeps and emission caps

Two higher-level helpers build on the carbon-price lever. `carbon_sweep` solves a sequence of increasing carbon prices, warm-starting each from the previous solution (a homotopy that lets high prices converge), and returns the emissions frontier:

```
sweep, base = carbon_sweep(cal, 0.0:20.0:400.0)      # price -> emissions
```

`solve_emission_cap` uses that frontier to find the smallest carbon price that holds global CO_2 at or below a target (an NDC-style cap):

```
res = solve_emission_cap(cal, 2.30)   # target in Gt (model units)
@info "cap" price=res.carbon_price emissions=res.emissions achievable=res.achievable
```

Scanning the warm-stepped frontier is more robust than a naive bisection from the benchmark, which fails at high prices.

A.12 Full-resolution note

The pipeline above aggregates to a coarse grouping for solving. The model can also be built at the fine 63-sector resolution by aggregating with the fine concordance and passing representative energy-commodity codes:

```
agg_fine = aggregate_gtap_sam(bal; concordance=gtap_fine63_concordance())
cal_fine = calibrate_sam(agg_fine; separate_land_natres=true)
m_fine   = build_static_model(cal_fine;
                  coal=["coa"], oil=["oil"], gas=["gas"],
                  elec_fossil=["elyff"], elec_clean=["elycl"])
```

At fine resolution the model is still square and NaN-free, but PATH is slower: the intermediate-demand block scales as regions×sectors^2, the basis factorisation of the larger MCP is heavier, and the fine benchmark is not always an exact fixed point (a handful of commodities with near-zero Armington denominators do not reproduce). It does solve to `LOCALLY_SOLVED` once the convergence tolerance is set to a size-appropriate 10^{-3} (an absolute residual that is $\approx 10^{-9}$ relative to the million-USD flows). For routine work, however, the coarse grouping is the intended configuration: it is an exact fixed point and solves essentially instantly, which matters because dynamics and scenario sweeps re-solve the model dozens of times.

A.13 Human-development runs

The human-development module (Chapter 3) is switched on with two build keywords: `human_dev=true` and an `HDParams` bundle. Everything else about the run is unchanged.

```
hd = hd_params_from_wb(cal)                     # observed WDI levels & shares (Africa)
```

```
# hd = default_hd_params(cal)               # illustrative defaults elsewhere

base_kw = merge(gtap_med30_sets(), (land_cet=true, natres_supply=true))
m, st   = solve_cal(cal; build_kw=merge(base_kw, (human_dev=true, hd=hd)))

value.(m.jm[:SDG4])     # primary-completion rate
value.(m.jm[:SDGVAL])   # SDG3 health, SDG6W water, SDG6S sanitation
value.(m.jm[:QHD])      # real service delivery by government function
```

A no-shock solve with `human_dev=true` must return every indicator at its base level; that is the module's own version of the homogeneity test and is worth running once per country before any scenario. A fiscal scenario is then a departure from it:

```
cal2, hd2 = with_gov_spending(cal, hd; education=0.065, health=0.035,
                              water=0.006, sanitation=0.006, energy=0.01)
m2, _ = solve_cal(cal2; starts=solution_starts(m),
                  build_kw=merge(base_kw, (human_dev=true, hd=hd2)))
```

Large fiscal reallocations move a lot of the model at once, so warm-starting from the base solution (`starts=solution_starts(m)`) is worth the line.

In a recursive run the same two keywords additionally close the between-period feedbacks (H-23)–(H-26), and the result frame gains the human-development panel alongside the economic variables:

```
df = run_recursive(cal; nperiods=14, base_year=2017,
                   human_dev=true, hd=hd, build_kw=base_kw)
```

The panel carries `SDG4`, `SDG3`, `SDG6W`, `SDG6S`, `SHENTRY`, `QHPC`, `INFRIDX` (and each transport mode), `ENERGIDX`, and `QENR`, `GRAD`, `EDUQUAL`, `SHPASS` by cycle, plus the realised feedback multipliers `HK_labgrow_sk`, `HK_labgrow_un` and `HK_healthprod` — so the labour-supply and productivity effects the module fed back into the economy are visible rather than implicit. The end-to-end driver is `examples/run_human_dev.jl`.

A.14 Coupling a satellite model

A satellite model is coupled through the EDIS registry, which resolves its interchange file, its concordance and its lever:

```
edis_manifest()                     # the whole coupling map
spec = edis_model("fishery")        # one satellite
link = apply_edis(cal, spec, "catch_path.csv", "uga";
                  base_year=2017, nperiods=14)
df   = run_recursive(cal; link.kw..., nperiods=14)
```

The levers compose: a scenario may move sectoral productivity, freight costs, the generation mix and the budget at once, because each writes to a different injection point. Two drivers exercise the layer end to end — one that couples every satellite at once, and the invariant suite that asserts the base-year fixed point lever by lever:

```
julia --project=. --pkgimages=no examples/run_edis_all.jl uga 14
julia --project=. --pkgimages=no test/test_bridges.jl
```

A.15 A note on running Julia here

On the EDIS workstation, Windows Application Control blocks freshly written precompilation DLLs, so any run that invalidates the precompile cache dies with an `Error opening` `package file ... An Application Control policy has blocked this file`. The failure is intermittent — it bites only when the cache is stale — so a run can succeed and the next one fail. Every driver should therefore be invoked with precompiled package images disabled:

```
julia --project=. --pkgimages=no examples/run_gtap_med30.jl ken
```

The `JULIA_PKGIMAGES` environment variable is not honoured for this; it must be the command-line flag.

A.16 Outputs

Solution extraction (`Results.jl`) writes the solved variables to a tidy `DataFrame` and an Excel workbook; `Plotting.jl` produces static (by-sector bar charts), dynamic (time-path line charts) and carbon-price figures and saves them as PNGs. The balanced SAM itself can be written to an Excel workbook (`ExcelWriter.jl`, `EngineBridge.jl`) for inspection. A typical driver ends by persisting the solution:

```
rows = DataFrame(variable=String[], value=Float64[])
for v in all_variables(m.jm); push!(rows, (name(v), Float64(value(v)))); end
XLSX.openxlsx("results/static_USA_CHN_DEU.xlsx", mode="w") do xf
    XLSX.rename!(xf[1], "solution")
    XLSX.writetable!(xf[1], collect(eachcol(rows)), names(rows))
end
```

Appendix B

The CES and CET functions

This appendix derives, in full, the two functional forms on which almost the entire model rests: the constant-elasticity-of-substitution (CES) function used for cost-minimising input demands and for the utility/aggregation nests, and the constant-elasticity-of-transformation (CET) function used for revenue-maximising output allocation. The derivations explain *why* the compact two-line template (CES-P)–(CES-D) of Section 2.2 and the CET relations (T-7)–(T-8) take the form they do, why benchmark prices of 1 make calibration trivial, and how the elasticities map to the model's behavioural responses. The treatment parallels Appendix A of the ENVISAGE documentation but is specialised to the two-input nests that CDCGE actually uses.

B.1 The CES cost-minimisation problem

A producer (or a consumer sub-nest) combines inputs $X_1, \ldots, X_n$ to form an aggregate V according to the CES technology

$$V \;=\; A\Big[\textstyle\sum_i a_i(\lambda_i X_i)^{\rho}\Big]^{1/\rho}, \tag{B.1}$$

where a_i are (primal) share parameters, λ_i are input-specific efficiency (technology) parameters, A is a neutral shift parameter, and ρ is the CES exponent. The agent chooses inputs to minimise expenditure $\sum_i P_i X_i$ at given input prices P_i subject to producing a target V. Forming the Lagrangian

$$\mathcal{L} = \sum_i P_i X_i + \Lambda\Big(V - A\big[\textstyle\sum_i a_i(\lambda_i X_i)^{\rho}\big]^{1/\rho}\Big),$$

the first-order conditions are $P_i = \Lambda\, a_i A^{\rho} \lambda_i^{\rho} X_i^{\rho-1} V^{1-\rho}$. Multiplying by X_i, summing, and using (B.1) shows that the multiplier Λ equals the aggregate (dual) price P defined by $P{\cdot}V = \sum_i P_i X_i$. Solving the first-order condition for X_i and substituting the *substitution elasticity* $\sigma = 1/(1-\rho)$ gives the conditional input demand

$$X_i \;=\; \alpha_i\,(A\lambda_i)^{\sigma-1}\Big(\frac{P}{P_i}\Big)^{\sigma} V, \qquad \alpha_i = a_i^{\sigma}, \tag{B.2}$$

and, by inserting (B.2) back into the zero-profit condition $P \cdot V = \sum_i P_i X_i$, the *dual price* (cost function)

$$P \;=\; \frac{1}{A}\Big[\textstyle\sum_i \alpha_i\,(P_i/\lambda_i)^{1-\sigma}\Big]^{1/(1-\sigma)}. \tag{B.3}$$

Equations (B.2)–(B.3) are the workhorse pair: demand for input i is a volume share of the aggregate that responds to the relative price P/P_i with elasticity σ, and the aggregate price is a CES aggregator of the component prices with the dual exponent $1-\sigma$.

B.2 Calibration with unit benchmark prices

In CDCGE all technology parameters are initialised to $A = \lambda_i = 1$ (they are levers reserved for dynamics, e.g. AEEI). Then (B.2) at the benchmark, with $\bar{P} = \bar{P}_i = 1$, reduces to $\bar{X}_i = \alpha_i \bar{V}$, so the dual share is simply the benchmark *volume* share $\alpha_i = \bar{X}_i/\bar{V}$, which (because prices are 1) equals the benchmark *value* share $\theta_i = \bar{v}_i / \sum_k \bar{v}_k$. This is precisely why `ces2!` (Section 2.2) is passed the benchmark values $\bar{v}_k$ and forms θ_k internally: the calibration of every CES nest is the trivial "share = benchmark value share," and no separate share-parameter file is needed. Substituting θ_k into (B.2)–(B.3) gives exactly the model equations (CES-D) and (CES-P) of Section 2.2.

B.3 The two-input case and budget shares

CDCGE uses only *two-input* CES nests (every node has a left and a right child), so $n = 2$ throughout. With shares θ and $1-\theta$ the dual price is $P^{1-\sigma} = \theta P_A^{1-\sigma} + (1-\theta) P_B^{1-\sigma}$ and the demands are $X_A = \theta(P/P_A)^\sigma V$, $X_B = (1-\theta)(P/P_B)^\sigma V$. The budget share of input i is

$$s_i = \frac{P_i X_i}{P V} = \theta_i \left(\frac{P}{P_i}\right)^{\sigma-1},$$

a function of prices alone. The elasticity of the aggregate price with respect to a component price equals that budget share, $\partial \ln P / \partial \ln P_i = s_i$, and the matrix of conditional (Hicksian) own- and cross-price demand elasticities at constant V is $\varepsilon_{ij} = \sigma(s_j - \delta_{ij})$, where δ_{ij} is the Kronecker delta. Because $\sigma > 0$, the two inputs in every nest are gross substitutes: a rise in the price of one shifts demand toward the other, with the strength of the shift governed by σ.

B.4 The three special cases handled by the code

The CES form is singular at certain elasticity values, and CDCGE's `ces2!` handles each exactly:

- **Leontief**, $\sigma = 0$ ($\rho \to -\infty$). Inputs are used in fixed proportions: $X_i = (\alpha_i/\lambda_i)V/A$ and $P = \frac{1}{A}\sum_i \alpha_i (P_i/\lambda_i)$. CDCGE applies this at the production top tier (P-3)–(P-4) and the non-energy intermediate bundle (P-6): the bundle's composition does not respond to relative prices, only its scale does. The dual price is the linear, share-weighted average of component prices — which is exactly the form of (P-5), written so that $PND1 = 1$ at the benchmark.

- **Cobb–Douglas**, $\sigma = 1$ ($\rho = 0$). The primal and dual both become geometric means; budget shares are constant at α_i. `ces2!` detects $|\sigma - 1| < 10^{-6}$ and emits the geometric-mean dual $P = \prod_i P_i^{\theta_i}$. Government and investment final demand (D-8)–(D-9) are Cobb–Douglas in this sense (constant value shares).

- **Perfect substitution**, $\sigma \to \infty$ ($\rho = 1$). The law of one price holds, $P_i = \lambda_i A P$, and the aggregator is linear. CDCGE does not use an infinite elasticity in any nest, but the high power-supply elasticity $\sigma_{pow} = 3$ approaches this regime, which is why fossil and clean electricity are near-substitutes from the buyer's side.

A fourth degenerate case — a nest with a zero-benchmark child — is not a standard CES special case but a data feature; `ces2!` pins the inactive child to ε and prices the parent from the single active child ($P = P_A$), as described in Section 2.2.

B.5 Comparative statics and the interpretation of σ

The substitution elasticity measures the curvature of an isoquant: it is the proportional change in the input ratio X_i/X_j induced by a proportional change in the relative price P_j/P_i,

$$\sigma = \frac{\partial \ln(X_i/X_j)}{\partial \ln(P_j/P_i)}.$$

A small σ (e.g. the 0.5 used for inter-fuel substitution) means input proportions are rigid: a carbon price that raises the relative price of coal shifts the coal/gas ratio only modestly in the short run. A large σ (e.g. the 3.0 used for the generation mix) means proportions are flexible: the same relative-price change shifts the fossil/clean electricity ratio strongly. This is the precise sense in which the calibrated elasticities encode the model's mitigation responsiveness, and it is why the choice of σ_{pow}, σ_{nely} and σ_{olg} matters for the model's emission-reduction responsiveness.

B.6 The CET function for output allocation

The CET function is the revenue-maximising mirror image of the CES. A sector with gross output XP allocates it between the domestic market XD and exports XET to maximise revenue $P_D\, XD + P_E\, XET$ subject to the transformation frontier

$$XP \;=\; \left[\gamma^{cd} XD^{1+\omega} + \gamma^{ce} XET^{1+\omega}\right]^{1/(1+\omega)},$$

where $\omega > 0$ is related to the transformation elasticity ψ_{et} by $\psi_{et} = 1/(\omega)$ in the convention used here. The first-order conditions give the supply allocations

$$XD = \bar{s}^{cd}\left(\frac{P_D}{P_X}\right)^{\psi_{et}} XP, \qquad XET = \bar{s}^{ce}\left(\frac{P_E}{P_X}\right)^{\psi_{et}} XP,$$

which are exactly the model equations (T-7)–(T-8): output flows toward whichever market offers the higher relative price, with the responsiveness set by ψ_{et}. The aggregate (revenue) price P_X is the CET dual, a transformation aggregator of P_D and P_E with the benchmark shares $\bar{s}^{cd}, \bar{s}^{ce}$; in CDCGE P_X is determined implicitly by the zero-profit and output-allocation identities (P-1)–(P-2) together with the market-clearing complementarities, rather than by a separate dual equation, which keeps the system square. The key contrast with the CES is the *sign* of the price in the demand expression: in the CES the component price is in the denominator (higher own-price $\Rightarrow$ less demand), whereas in the CET it is in the numerator (higher own-price $\Rightarrow$ more supply to that market), reflecting substitution versus transformation.

B.7 The bilateral (second-level) Armington nest

The import side adds a second CES nest that sources the import composite across partner regions, and it is worth noting how the trade elasticity that a single exporter faces emerges from the two-level structure. With a top Armington elasticity σ_{arm} (domestic vs. aggregate imports) and a second-level elasticity σ_w (sourcing across exporters), the demand for imports from a particular source s has an own-price elasticity that is a share-weighted combination of the two, $\varepsilon^w_s \approx (1-s_s)\sigma_w + s_s[(1-s_m)\sigma_{arm} + s_m\varepsilon^d]$, where s_s is source s's share in the import composite, s_m the import share in absorption, and ε^d the overall demand elasticity. The practical implication is that the high sourcing elasticity $\sigma_w = 4$ governs *re-allocation across trade partners* (the response to a bilateral tariff or a partner's price change), while the lower top elasticity $\sigma_{arm} = 2$ governs the *domestic-versus-imported* margin. CDCGE implements this exactly as the two CES levels (T-1)–(T-3) and (T-5)–(T-6).

Appendix C

The household demand system

This appendix derives the linear expenditure system (LES) used for household demand (Section 2.4) from its Stone–Geary utility foundation, gives its elasticities, and shows how CDCGE calibrates it from the benchmark consumption vector and a single Frisch parameter. It corresponds to the part of ENVISAGE Appendix B that CDCGE actually implements; the ELES, AIDADS and CDE systems documented there are *not* part of CDCGE.

C.1 Stone–Geary utility and the LES

The household maximises the Stone–Geary utility function

$$u \;=\; \prod_k (x_k - \gamma_k)^{\beta_k}, \qquad \sum_k \beta_k = 1, \quad x_k > \gamma_k,$$

where γ_k is the *subsistence* (committed, floor) quantity of good k and β_k is the marginal budget share, subject to the budget constraint $\sum_k P_k x_k = Y$, with Y the income available for consumption. The first-order conditions yield the linear expenditure system

$$x_k \;=\; \gamma_k + \frac{\beta_k}{P_k}\Big(Y - \textstyle\sum_j P_j \gamma_j\Big) \;=\; \gamma_k + \frac{\beta_k}{P_k} Y^{sup}, \tag{C.1}$$

where $Y^{sup} = Y - \sum_j P_j \gamma_j$ is *supernumerary income* — income net of total subsistence spending. Demand is thus the sum of a fixed committed quantity plus a marginal share β_k of supernumerary income deflated by the good's price. Equations (D-1)–(D-3) of the model are exactly (C.1): (D-1) defines Y^{sup} (with $Y = YD - Sh$, disposable income net of saving), (D-2) applies (C.1) to each non-energy good, and (D-3) applies it to the aggregate energy bundle (which is then disaggregated by the energy nest (D-4)–(D-7)).

C.2 LES elasticities

Differentiating (C.1) gives the income (expenditure) elasticity $\eta_k = \beta_k / s_k$, where $s_k = P_k x_k / Y$ is the average budget share, and the own-price elasticity $\varepsilon_k = \gamma_k(1 - \beta_k)/x_k - 1$. Two features matter for CDCGE. First, the income elasticity exceeds, equals or falls short of one as the marginal share β_k exceeds, equals or falls short of the average share s_k: goods with a high marginal share are luxuries, those with a high subsistence quantity are necessities. Second, the LES does not allow inferior goods or gross complementarity among the broad commodities; that is a known limitation of the form, and it is why the *energy* commodities are pulled out of the LES basket and given their own CES nest (D-4)–(D-7), where genuine inter-fuel substitution can be represented.

C.3 The Frisch parameter and calibration

The LES is calibrated from the benchmark consumption vector $\bar{C}_{r,i}$ and a single additional parameter, the Frisch parameter ϕ (the elasticity of the marginal utility of income with respect to income, a negative number). CDCGE uses $\phi = -1.5$ and assumes unit income elasticities, which fixes the marginal budget shares and the subsistence quantities directly:

$$\beta_i = \frac{\bar{C}_{r,i}}{\bar{C}_r^{tot}}, \qquad \gamma_i = \bar{C}_{r,i}\Big(1 - \frac{1}{|\phi|}\Big), \qquad Y_r^{sup,\,\text{bench}} = \frac{\bar{C}_r^{tot}}{|\phi|}. \tag{C.2}$$

The relationship between the Frisch parameter and the subsistence share is the standard one: $|\phi|$ is (minus) the ratio of total expenditure to supernumerary income, so a Frisch parameter of -1.5 implies that subsistence spending is $1 - 1/1.5 = 1/3$ of the budget and supernumerary income is $2/3$. The energy bundle is calibrated the same way with $\bar{C}_r^{nrg}$ in place of $\bar{C}_{r,i}$. With benchmark prices of 1, substituting (C.2) into (C.1) returns the benchmark consumption exactly, so the LES reproduces the data. This is the calibration coded in the household block (`blocks/DemandBlock.jl`; the `betaN`, `gamN`, `beta_nrg`, `gam_nrg` terms).

C.4 Government, investment and the savings decision

Government and investment demand are Cobb–Douglas (constant value shares), calibrated trivially from the benchmark government and investment vectors (Section A.7, (Cal-8)). Household saving is treated as a fixed average propensity out of disposable income (Y-12), with the propensity $\overline{aps}_r$ read from the benchmark (Cal-14); this is the LES (not ELES) treatment, in which the saving decision is separable from the within-period allocation of consumption. The level of investment is then savings-driven through the financing identity (Y-16), closing the macro side.

Appendix D

Analytics of the dynamics

This appendix collects the analytics behind the recursive dynamics (Section 2.11) and the climate discretisation (Section 2.10).

D.1 Capital accumulation and the stationary benchmark

The capital stock follows the perpetual-inventory law (G-1), $K_{t+1} = (1 - \delta)K_t + I_t$. For the benchmark to be a stationary point of a no-growth, no-shock run, investment must exactly replace depreciation, $I_0 = \delta K_0$, i.e. $K_0 = I_0/\delta$. CDCGE initialises the capital tracker at exactly this value, $K_{r,0} = \bar{I}_r/\delta$ (with the benchmark investment $\bar{I}_r$ from the SAM), so that $g^K_{r,0} = K_{r,1}/K_{r,0} = (1 - \delta) + I_0/K_0 = (1 - \delta) + \delta = 1$: the capital stock is constant in the reference run, and any deviation in the capital path is a genuine response to growth or to a shock. Sectoral capital is not tracked separately; the model carries the aggregate capital value Ks (Y-13) and the depreciation allowance $DeprY$ (Y-14), and the between-period growth factor is applied uniformly to the capital endowment.

D.2 Labour-augmenting productivity and balanced growth

The combined labour growth factor (G-2) multiplies population growth by productivity growth, $(1 + g_{l\bullet})(1 + g_{tfp})$, applied to the labour endowments only. Because capital grows endogenously through accumulation, in a balanced reference run the capital–labour ratio in efficiency units tends to a constant: investment rises with output, the capital stock grows in step with effective labour, and factor prices are stationary. The skill-differentiated labour growth ($g_{ls} > g_{lu}$ by default) shifts the labour composition toward skilled labour over time, which — through the value-added nest (P-7), (P-9) — gradually raises the skilled wage premium, a stylised representation of skill-biased growth.

D.3 Autonomous energy efficiency and decoupling

AEEI (G-3) scales the benchmark intermediate-use coefficients of the emitting commodities down by a fixed rate each period. Holding output fixed, this lowers energy use and hence emissions proportionally; with output growing, emissions grow only if the scale effect outpaces the efficiency effect. The net emission trajectory in a reference run is therefore a race between output growth (which raises energy use) and AEEI plus capital deepening (which lower energy intensity); in the calibrated default, the two roughly offset, so reference emissions are broadly flat-to-declining over the horizon.

D.4 The climate discretisation

The climate module (Cl-1)–(Cl-7) is a discrete-time, five-year-step linear-Gaussian carbon cycle coupled to a two-box energy-balance temperature model and a quadratic damage function, in the DICE tradition. The carbon cycle (Cl-1)–(Cl-3) is a Markov transfer among three reservoirs (atmosphere, upper ocean/biosphere, deep ocean) with the period's emissions added to the atmospheric box; the transfer matrix $\Phi = [\phi_{ij}]$ is column-conservative (each column of the carbon-mass transition sums to one up to the emission injection), so carbon mass is conserved. Radiative forcing (Cl-4) is logarithmic in the atmospheric-carbon ratio (the standard $\eta \log_2(MAT/MAT_{pre})$ relation with $\eta = 3.6813$ W/m^2 per CO_2 doubling), plus an exogenous non-CO_2 forcing. The temperature system (Cl-5)–(Cl-6) relaxes the atmospheric temperature toward its forcing-implied equilibrium at a rate set by ξ_1, with the climate-feedback term $\lambda = \eta/\mathrm{ECS}$ encoding the equilibrium climate sensitivity (default 3°C per doubling), and exchanges heat with the deep ocean. The damage factor (Cl-7) is the reciprocal-quadratic $1/(1 + \pi_2 T^2)$, an output multiplier below one. The module is stepped *after* each period's economic equilibrium is solved, and (optionally) feeds the next period's factor productivity through (G-4); it is never inside the MCP, exactly as ENVISAGE places its climate block outside the equilibrium system.

Appendix E

The analytical SAM

The Social Accounting Matrix is the accounting backbone of the model: it is a square table whose (row, col) cell records a payment from the column account to the row account, and which is *balanced* when every account's row total (its receipts) equals its column total (its outlays). This appendix describes the CDCGE SAM's account structure and the identities it encodes.

E.1 Account structure

The CDCGE SAM (before aggregation) has the account types in Table E.1. There is one sector account per region–product pair (playing both activity and commodity roles, since GTAP's make matrix `MAKB` is diagonal), one account per region–factor pair, three final-demand accounts per region, and seven tax accounts per region.

Table E.1: CDCGE SAM account types.

Account	Label pattern	Role
Sector	`SEC:`r`:`i	activity output / commodity supply for product i in region r
Factor	`FAC:`r`:`f	primary endowment f (land, labour skills, capital, NRS)
Household	`HH:`r	household income and consumption
Government	`GOV:`r	government revenue and expenditure
Investment	`INV:`r	savings pool and investment demand
Taxes	`PTAX/ITAX/MTAX/`	production, indirect, import, export,
	`ETAX/VTAX/CTAX/DTAX:`r	factor-use, carbon, direct taxes
Rest-of-World	`ROW` (or full region)	the world bloc, anchoring trade

E.2 The balance identities

Reading the SAM by account type recovers the model's accounting identities. The *sector* row total (sales of commodity i: intermediate use + final demand + exports) equals its column total (cost of activity i: intermediate inputs + value added + taxes) — this is the goods-market balance (T-4) plus the zero-profit condition (P-1). The *factor* row total (factor income paid by sectors) equals its column total (factor income received by households) — the factor-income identity (Y-1). The *household* row total (factor income + transfers) equals its column total (consumption + saving + direct tax) — the household budget (Y-10)–(Y-12). The *government* balance is revenue = expenditure + public saving (Y-9), (Y-15). The *investment* balance is the savings pool (household + government + foreign saving) = investment demand (Y-16). And the *Rest-of-World/ tax* accounts close the current account and the fiscal accounts. A balanced SAM is therefore a complete, consistent snapshot of the circular flow, and calibrating to it (Chapter 4) guarantees that the model reproduces it as an equilibrium.

E.3 Why balancing is necessary, and the RAS update

The raw SAM reconstructed from the GTAP data is close to balanced but not exactly so, for three reasons: rounding in the GTAP value-flow headers; the value-added-plus-tax decomposition of the column totals, which need not exactly match the row totals; and a small number of one-sided accounts (e.g. commodities that have costs but no priced output in the data), which are economically repaired (routing unrecorded output to investment, income to capital) before balancing. The RAS / iterative-proportional-fitting update (Section A.5) restores exact balance by alternately scaling rows and columns to a midpoint target $t_k = \frac{1}{2}(\mathrm{row}_k + \mathrm{col}_k)$, judged on the maximum relative gap so that the criterion is scale-invariant across the many orders of magnitude that SAM values span. Convergence to machine precision typically takes a few hundred iterations.

Appendix F

The logistic outcome function

Appendices B and C derived the two functional forms on which the economy rests. This appendix does the same for the form on which the human-development module rests (Chapter 3): the sigmoid that maps a determinant aggregate into an education behaviour share or an SDG indicator, and the constant-elasticity aggregator that produces the determinant.

F.1 The constant-elasticity determinant aggregate

Each outcome depends on several determinants — service delivery, income, infrastructure, energy access, other outcomes — which are measured in incommensurable units: real spending in million USD, an index, a percentage, a wage ratio. The module makes them commensurable by entering each as a *ratio to its own base year*, $\hat{x}_k = x_k/\bar{x}_k$, and aggregating them multiplicatively with constant elasticities:

$$Z \;=\; \prod_k \hat{x}_k^{\phi_k}. \tag{L-1}$$

Three properties follow immediately, and each is used.

1. **Base-year normalisation.** At the benchmark every $\hat{x}_k = 1$, so $Z_0 = 1$ regardless of the elasticities. This is what makes the benchmark an exact fixed point of the whole module no matter how the ϕ_k are set.
2. **Elasticity interpretation.** $\partial \log Z/\partial \log x_k = \phi_k$, so each ϕ_k is directly the elasticity of the determinant aggregate with respect to that determinant — readable, and calibratable against a target.
3. **Substitutability.** The multiplicative form means determinants compensate rather than bind: infrastructure that never arrives can be partly offset by higher spending. Where that is not the desired behaviour — where a determinant is a genuine prerequisite — the modelling response is a large ϕ_k, not a change of functional form.

Note that (L-1) alone is scale-free: doubling every determinant doubles nothing in particular but pushes Z up without limit. That is why it is not the outcome function itself but only its argument.

F.2 The logistic and its calibration

The outcome is a sigmoid in Z,

$$SHR(Z) \;=\; ext + \frac{\alpha}{1 + \exp(\gamma + \beta Z)}, \tag{L-2}$$

with ext the extreme value the outcome approaches (a completion share approaches 1, an access percentage approaches 100), β the exogenous slope, and α, γ determined by calibration. Two conditions pin them down.

First, the function must *reproduce the base year*: at the base determinant $Z_0 = 1$ it must return the observed base outcome s_0. Second, its *inflection point* — where the marginal return to the determinant is greatest — must sit at ιZ_0, with ι the inflection multiplier (MAMS `GAMMAEDUDEF`/`GAMMAMDGDEF`). Since (L-2) inflects where $\gamma + \beta Z = 0$, the second condition gives

$$\gamma \;=\; -\beta\,\iota\,Z_0 \;=\; -\beta\iota, \tag{L-3}$$

and substituting into the first gives the amplitude

$$\alpha \;=\; (s_0 - ext)\,\big(1 + \exp(\gamma + \beta Z_0)\big) \;=\; (s_0 - ext)\,\big(1 + e^{\beta(1-\iota)}\big). \tag{L-4}$$

With the symmetric MAMS default $\iota = 1$ the base year sits exactly at the inflection point, the exponential is 1, the denominator is 2, and $\alpha = 2(s_0 - ext)$. Because $s_0 < ext$ for any outcome below its ceiling, $\alpha < 0$, and SHR rises toward ext as Z rises — which is the intended sign.

F.3 Why a sigmoid

Three shape properties matter, and (L-2) is essentially the simplest form that has all three.

- **Bounded above.** $SHR \to ext$ as $Z \to \infty$: no amount of spending drives a completion rate past 100 %. A constant-elasticity or log-linear outcome equation has no such ceiling and will happily report impossible coverage under a large enough budget.
- **Diminishing returns near the ceiling.** The marginal effect of a determinant,

$$\frac{\partial SHR}{\partial Z} \;=\; -\frac{\alpha\beta\exp(\gamma + \beta Z)}{\big(1 + \exp(\gamma + \beta Z)\big)^2}, \tag{L-5}$$

  falls away on both tails. The last ten percentage points of sanitation coverage cost far more than the first ten — the single most robust empirical regularity in SDG costing, and the reason a linear cost-per-point extrapolation systematically understates the cost of the final stretch.
- **Slow response from a very low base.** On the lower tail the response is also weak: a country far below the inflection point needs to move several determinants before outcomes respond visibly. This is what generates the "big push" result MAMS is known for — a coordinated package across services outperforms the same money spent on one service.

The slope β controls how sharply the transition happens and is the natural per-country calibration handle: raise it and a given change in service delivery moves the outcome further. Because α and γ are re-derived from (L-3)–(L-4) whenever β changes, re-calibrating β never breaks the base-year reproduction. The MAMS practice of calibrating β so that a historical target year is hit is available here for exactly the same reason.

Appendix G

Glossary of variables, parameters and equations

This appendix lists the endogenous variables, the calibrated parameters and the equation blocks of the model, as a reference. The variable and parameter names match the source code; the equation labels match Chapter 2.

G.1 Endogenous variables

Table G.1: Endogenous variables of the static model.

Variable	**Description**
$XP_{r,i}$	gross output of sector i in region r
$ND1_{r,i}$	non-energy intermediate-input bundle
$VA_{r,i}$	value-added bundle
$KEF_{r,i}$	capital–skilled-labour–energy bundle
$KS_{r,i}$	capital–skilled-labour bundle
$EN_{r,i}$	energy bundle
$XELY_{r,i}$	electricity bundle (fossil + clean)
$NELY_{r,i}$	non-electric energy bundle
$OLG_{r,i}$	oil-and-gas bundle
$XN_{r,i,a}$	intermediate demand of commodity i by activity a
$XF_{r,f,i}$	demand for factor f by sector i
$XA_{r,i}$	Armington composite absorption of commodity i
$XD_{r,i}$	domestic-market demand/supply of commodity i
$XMT_{r,i}$	aggregate import composite
$XET_{r,i}$	aggregate export bundle
$XW_{exp,i,r}$	bilateral trade flow (exporter exp to importer r)
$XAc_{r,i}, XAg_{r,i}, XAi_{r,i}$	household, government, investment demand for i
$XCnrg_r$	household aggregate energy bundle
$XCely_r, XCnely_r, XColg_r$	household electricity, non-electric, oil-gas bundles
$Ysup_r$	household supernumerary income
$PX, PND1, PVA, PKEF,$ $PKS, PEN, PELY, PNELY, POLG$	producer, intermediate, value-added, KEF, KS, energy, electricity, non-electric, oil-gas prices
PA, PD, PMT, PE	Armington, domestic, import-composite, export prices
$WF_{r,f}$	factor price (wage/rental) of factor f
$PCnrg, PCely, PCnely, PColg$	household energy composite prices
$PNUM$	numéraire price (fixed to 1)
$YF_{r,f}$	factor income

Variable	Description
YH_r, YD_r	household income, disposable income
Sh_r, Sg_r, SI_r	household saving, government saving, investment outlay
$Ks_r, DeprY_r$	capital stock value, depreciation allowance
$YG_r, YGOV_{r,gy}$	total government revenue, revenue by instrument
$Emi_r, EmiGbl$	regional and global CO_2 emissions
$GDPMP_r, Welf_r$	nominal GDP at market prices, welfare (consumption) index
Factor-supply closures (Section 2.8.2), optional	
$PFlnd_{r,a}, PFnrs_{r,a}$	activity-specific land rent and natural-resource rent
$PTLand_r, TLand_r$	aggregate land price index and aggregate land supply
Human development (Chapter 3), optional	
$GHD_{r,gf}$	nominal government spending on function gf
$PHD_{r,gf}, QHD_{r,gf}$	service-delivery price index and real service delivery
$QHPC_r, GNEPC_r$	real household consumption and gross national expenditure per capita
$MIDX_{r,m}$	per-mode transport-infrastructure access index ($ROADIDX$, $RAILIDX$, $WATTRIDX$)
$INFRIDX_r$	aggregate transport-infrastructure access index (SDG 9)
$ENERGIDX_r$	energy-access index (SDG 7)
$ZSDG_{r,s}, SDGVAL_{r,s}$	SDG determinant aggregate and indicator, $s \in \mathcal{S}$
$EDUQUAL_{r,c}, ZEDU_{r,c}$	educational quality and education determinant aggregate, cycle c
$SHENTRY_r$	grade-1 net intake share
$SHPASS_{r,c}, SHCONT_{r,c}$	promotion/graduation and continuation shares, cycle c
$QENR_{r,c}, GRAD_{r,c}$	enrolment stock and annual graduates, cycle c
$SDG4_r$	primary-completion rate (SDG 4)

G.2 Calibrated parameters

Table G.2: Calibrated parameters (benchmark levels, shares and rates).

Parameter	Description
$\bar{X}_{r,i}$	benchmark gross output
$\bar{Z}_{r,i,j}$	benchmark intermediate use of i by j
$\bar{F}_{r,f,i}$	benchmark factor use
$\bar{a}^{nd1}_{r,i}, \bar{a}^{va}_{r,i}$	Leontief top-tier coefficients (intermediate, value added)
$\text{io\_coef}_{r,i,j}$	input–output coefficient $\bar{Z}/\bar{X}$
$\alpha^{va}_{r,f,i}$	factor share in value added
$\tau^p_{r,i}, \tau^i_{r,i}$	production and indirect tax rates
$\bar{C}_{r,i}, \bar{G}_{r,i}, \bar{I}_{r,i}$	benchmark household, government, investment demand
$\bar{s}^c_{r,i}, \bar{s}^g_{r,i}, \bar{s}^{inv}_{r,i}$	consumption, government, investment budget shares
$\beta_{r,i}, \gamma_{r,i}$	LES marginal budget shares and subsistence quantities
$\bar{s}^d_{r,i}, \bar{s}^m_{r,i}$	top-Armington domestic and import shares
$\bar{s}^{cd}_{r,i}, \bar{s}^{ce}_{r,i}$	CET domestic and export shares
$\bar{s}^w_{exp\to r,i}$	bilateral import source shares
$\bar{E}_{r,i}, \bar{M}_{r,i}$	benchmark total exports and imports
$\bar{XW}_{r,r',i}$	benchmark bilateral trade flows

Parameter	Description
$\bar{YF}_{r,f}, \bar{YH}_r$	benchmark factor income, household income
$\overline{aps}_r, \tau^d_r$	savings rate, direct-tax rate
$\bar{Sf}_r$	net foreign saving (current-account balance)
$\bar{GEXP}_r, \bar{INV}_r, \bar{GREV}_r$	benchmark government expenditure, investment, revenue
ρ_i	CO_2 intensity of commodity i
$\sigma_v, \sigma_{kef}, \sigma_k, \sigma_{erg}$,	production substitution elasticities
$\sigma_{pow}, \sigma_{nely}, \sigma_{olg}$	(Table 2.2)
$\sigma_{arm}, \sigma_w, \psi_{et}$	trade elasticities (Table 2.4)
$\sigma_{ce}, \sigma_{cnely}, \sigma_{colg}, \phi$	consumer elasticities and Frisch parameter
$\kappa^f, \kappa^h, \tau^v, \tau^m, \tau^e, \delta$	fiscal/depreciation parameters (default 0 except $\delta = 0.05$)
$\omega, \eta_{lnd}, \eta_{nrs}$	land CET, land supply and natural-resource supply elasticities
$\gamma_{r,a}, \overline{TLand}_r$	benchmark land shares by activity, benchmark aggregate land
$\overline{fsh}_{r,gf}, \overline{QHD}_{r,gf}$	base government budget share and real service delivery by function
$\overline{QENR}_{r,c}, \overline{GRAD}_{r,c}$	base enrolment and graduates by cycle
$\overline{SH}_\bullet$	base education behaviour shares: $\overline{SHENTRY}$ intake, $\overline{SHPASS}$ promotion, $\overline{SHCONT}$ continuation
$\overline{SDGVAL}_{r,s}, ext_\bullet$	base SDG levels and logistic ceilings
$\beta_\bullet, \iota, \alpha, \gamma$	logistic slopes, inflection multiplier, calibrated amplitude and intercept (Table 3.2)
$\phi^e_\bullet, \phi^h_\bullet, \phi^w_\bullet, \phi^s_\bullet$	education, health, water and sanitation determinant elasticities
$\phi^{el}, \phi^{eg}, w_m$	energy-access elasticities and infrastructure-mode weights
$\theta^{lab}, \theta^{hlt}$	graduation→labour-supply and health→productivity feedback elasticities
$\bar{p}_r, \pi_r$	base population scale and cumulative population ratio

G.3 Equation index

Table G.3: Equation blocks and their complementary variables.

Block	Equations
Production	(P-1) zero profit $\perp XP$; (P-2) output allocation $\perp PX$; (P-3)–(P-4) Leontief demands; (P-5)–(P-6) intermediate price and demand; (P-7)–(P-9) value-added/factor nests; (P-10)–(P-13) energy nest
Demand	(D-1) supernumerary income; (D-2)–(D-3) LES demands; (D-4)–(D-7) consumer energy nest; (D-8)–(D-9) government and investment demand
Trade	(T-1)–(T-3) top Armington; (T-4) commodity market clearing; (T-5)–(T-6) bilateral sourcing; (T-7)–(T-8) CET allocation; (T-9)–(T-10) export markets and RoW anchor
Income	(Y-1) factor income; (Y-2)–(Y-9) government revenue; (Y-10)–(Y-12) household income/saving; (Y-13)–(Y-14) capital and depreciation; (Y-15)–(Y-16) government saving and financing
Markets/closure	(M-fac) factor markets; (M-1) numéraire; (M-3)–(M-4) GDP and welfare
Factor supply	(F-1)–(F-4) land CET allocation, aggregate land price and supply, land income; (F-5)–(F-6) natural-resource supply and income

Block	Equations
Human development	(H-1)–(H-4) government spending by function; (H-5)–(H-8) consumption per capita and infrastructure access; (H-9) energy access; (H-10)–(H-13) the water, sanitation and health SDGs; (H-14)–(H-22) education quality, behaviour, cohort accounting and SDG 4; (H-23)–(H-26) the between-period labour-supply, productivity and population feedbacks
Logistic form	(L-1) determinant aggregate; (L-2) the sigmoid; (L-3)–(L-4) its calibration; (L-5) the marginal effect
Emissions	(E-1) regional emissions; (E-2) global emissions
Climate	(Cl-1)–(Cl-3) carbon cycle; (Cl-4) forcing; (Cl-5)–(Cl-6) temperature; (Cl-7) damage
Dynamics	(G-1) capital accumulation; (G-2) labour growth; (G-3) AEEI; (G-4) damage feedback
Calibration	(Cal-0)–(Cal-15) parameter recovery from the balanced SAM

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