Dynamics in ENVISAGE Model: Version 10.0

Dominique van der Mensbrugghe

Center for Global Trade Analysis (GTAP)
Department of Agricultural Economics
Purdue University

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Sources of dynamics

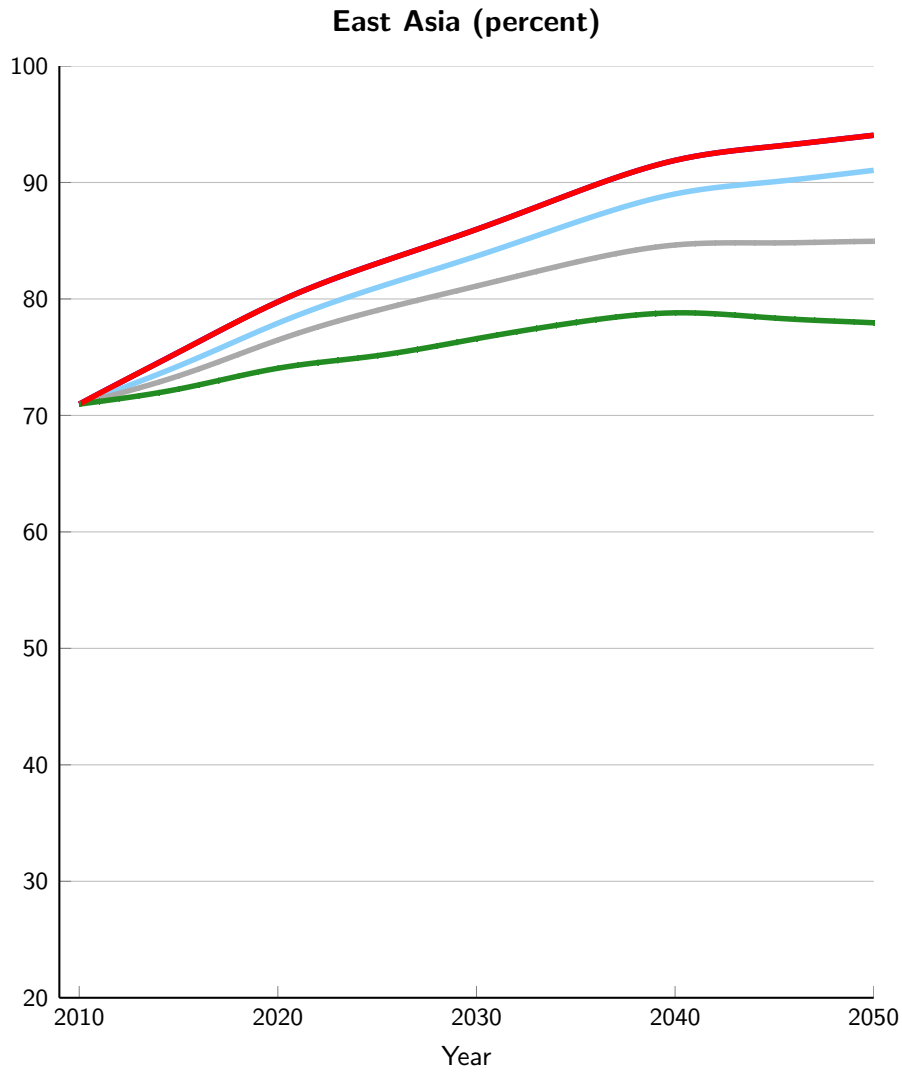
$$Y = F\left(K, L, T, N, \lambda^k, \lambda^l, \lambda^t, \lambda^n, ...\right)$$

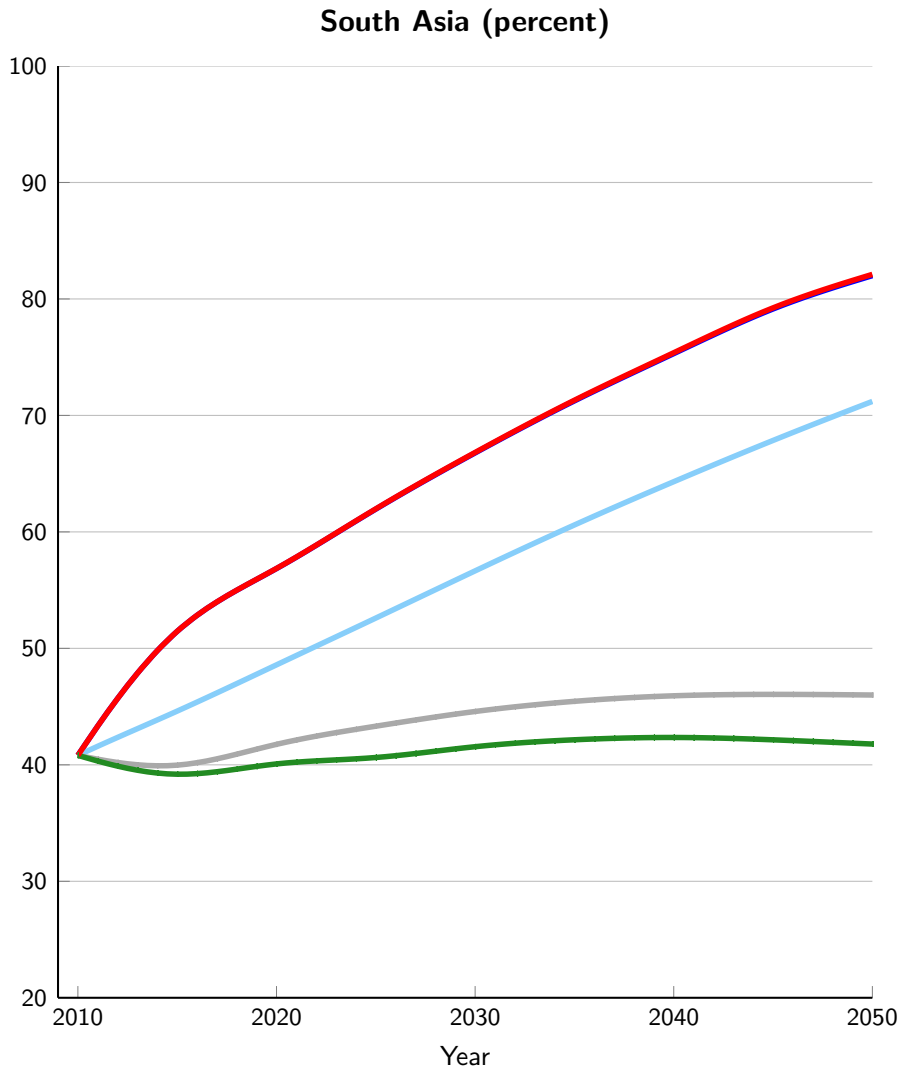
1. Labor supply growth (or decline!). A function of demographics and labor force participation rates. Typically exogenous.
2. Capital stock—depends on depreciation and past savings
3. Land is assumed to be on a supply curve
4. Natural resources also on supply curve—developing resource depletion modules for fossil fuels.
5. Most productivity growth is assumed to be labor-augmenting, i.e. Harrod neutral, with possibility of differentiation across sectors
6. Allow for efficiency improvement in the use of energy, international transportation, and yields in agriculture. Also have downward sloping cost curves for new technologies, such as solar electricity
7. Introducing preference shifts for energy bundles, trade, consumer demand (food for example)

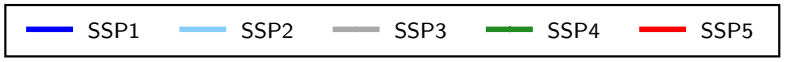
Labor

- Aggregate labor stock in period t is based on some assumptions of the growth of the population and the labor force participation rate: $L_t^s = \sum_{c,g} \varphi_{c,g,t} Pop_{c,g,t}$, where c refers to the population cohort and g gender and φ is the labor force participation rate. We typically equate labor force growth to the growth of the working age population (ages 15-64) with unchanged labor force participation.
- In the absence of any further information, we assume that growth is identical across skilled and unskilled workers. An alternative is to use assumptions about education growth rates (available from both IIASA and the World Bank) to drive the growth of skilled workers and derive the growth of unskilled workers residually.

Education: Secondary+ Level for Working-age Population







Capital stock

$$K_t = (1 - \delta)\, K_{t-1} + I_{t-1}$$

- Holds for aggregate capital stock. Allocation will be driven by supply/demand equilibrium.
- Equation needs to be altered when passing to multi-year time steps. It also makes equation endogenous. [One alternative is simply to set cumulative investment to $n \times I_{t-n}$. Perhaps suitable for short time periods.]

$$K_t = (1 - \delta)^n\, K_{t-n} + I_{t-n} \frac{(1+g)^n - (1-\delta)^n}{g + \delta} \text{ where } I_t = (1+g)^n I_{t-n}$$

Land and natural resources

- Supply curves calibrated to initial situation. Movements up and down supply curve.
- Building in new resource depletion modules for coal, oil and gas. Resources finite and non-renewable.

Productivity

- Two situations:
  1. Calibrate GDP to exogenous scenario, e.g. SSP
  2. Productivity is known, GDP is endogenous
- $Y = A \cdot F(K, L, \lambda^l, \lambda^k)$
- Y, K, L are known—three choices:
  1. Hicks neutral—calibrate on A (i.e. total factor productivity or TFP)
  2. Harrod neutral—calibrate on λ^l (i.e. labor augmenting technology growth)
  3. Solow neutral—calibrate on λ^k (i.e. capital augmenting technology growth)
- Also hybrid approaches.
  1. Balanced growth: $\frac{\lambda^k K}{\lambda^l L} = \chi$. Two equations two unknowns: λ^l and λ^k.
  2. Targeted capital/labor ratios by sector and year (Dixon and Rimmer). Use twists.

Productivity

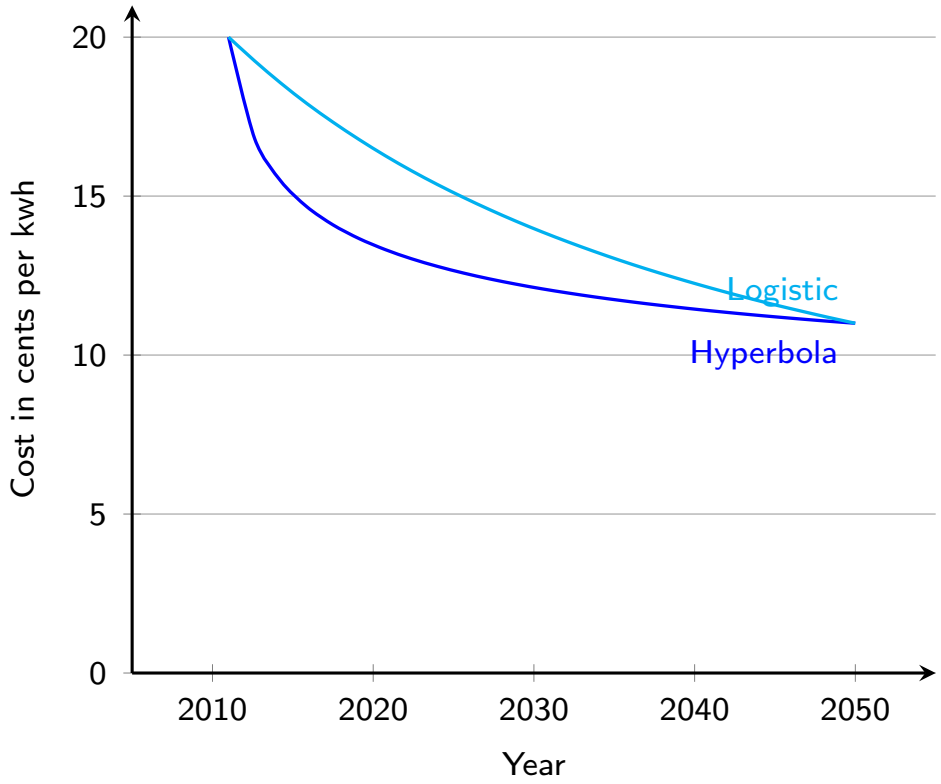
- ENVISAGE assumes labor-augmenting technology with differentiated productivity across sectors—higher in agriculture and manufacturing, i.e. calibrate labor productivity in services.
- Other technology elements in baseline:
  1. Autonomous energy efficiency improvement (AEEI). Assume 1% across the board, but should differentiate across regions, sectors and fuels. There are also physical constraints, e.g. in electricity production.
  2. Exogenous yield growth in crops and livestock.
  3. Exogenous improvements in international transport costs.
- Other optional technology elements:
  1. 'Make' module (λ^s), e.g. post-harvest losses
  2. Intermediate demand (λ^{io}), e.g. fertilizer, feed, food waste in value chain
  3. Consumer transition matrix (λ^c), e.g. household waste
  4. Iceberg parameter (λ^w), e.g. trade inefficiencies

Productivity

- Productivity growth is a 'gift' in ENVISAGE, i.e. there are no costs associated with productivity improvement.
- Currently testing a research and development (R&D) module for labor productivity growth—requires investments in R&D. R&D will explain some share of total labor productivity growth. Impacts also take time to take into effect—lagged distribution response.
- For waste, would like to link an 'x' percent decline in food losses and waste to '$y' billion in investment or other expenditures. See for example Purdue's PICS program.

Other dynamic components on production side

- Introduction of new energy technologies: e.g. carbon capture and storage, including BECCS—need cost structure AND preference parameters for energy/power bundles
- Cost curves, for example for wind and solar

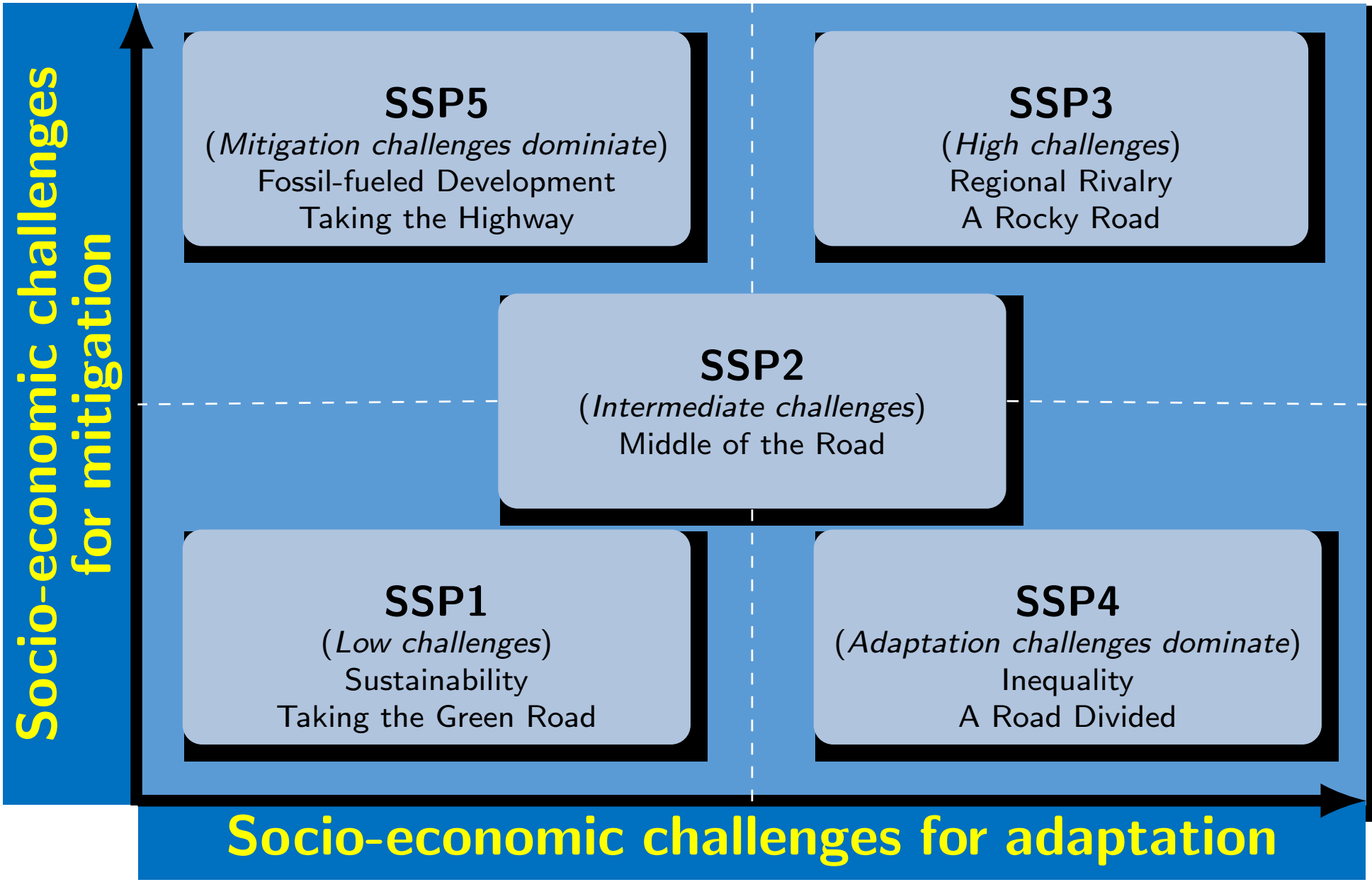


Preference shifters

- In the top level consumer demand function: Engel and Bennett Laws, other empirical regularities
- Armington trade system: autonomous shifts in import penetration
- Energy choices: renewable vs. conventional, electric vehicles etc.

Macro assumptions

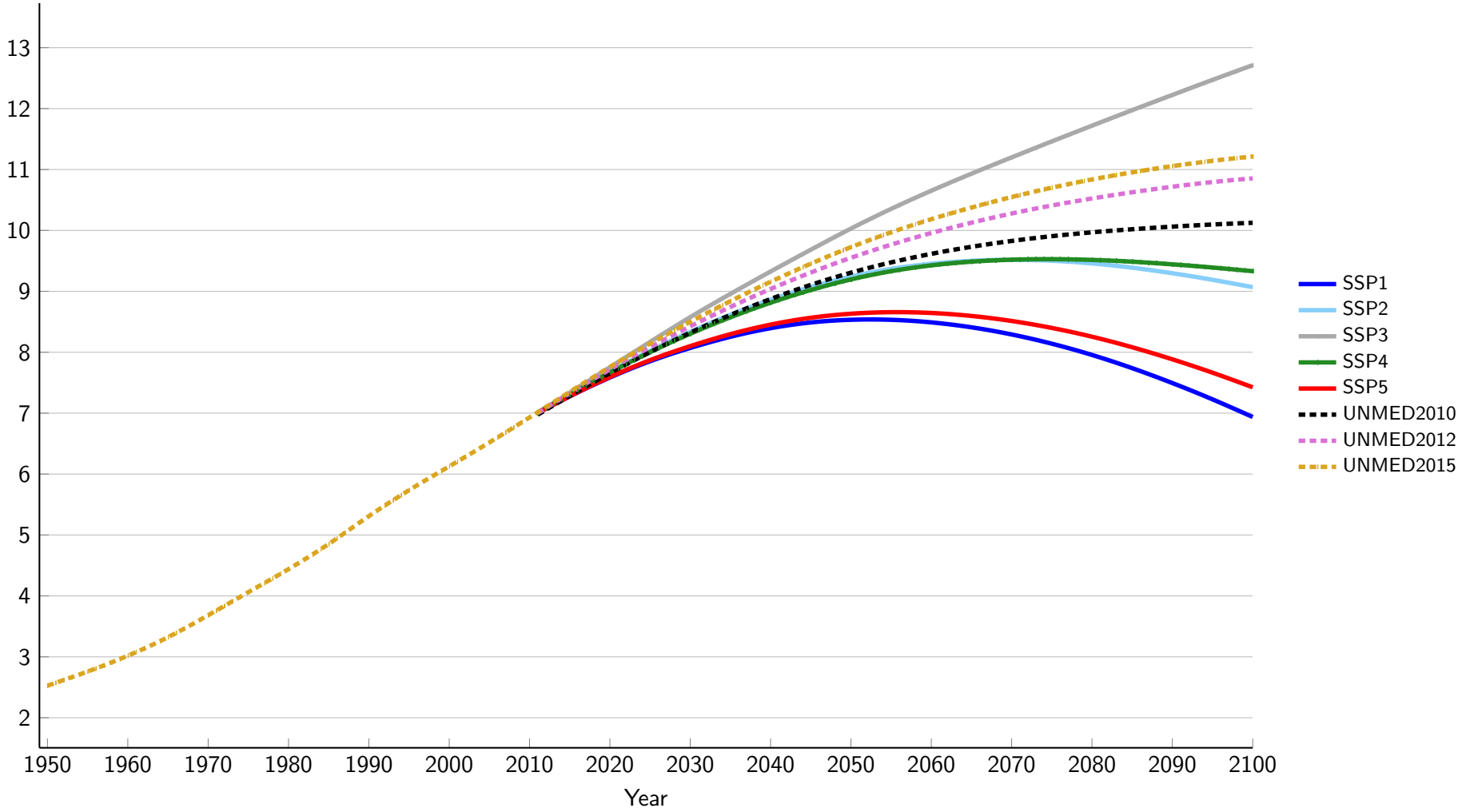
- Government expenditures and deficit—default: government expenditures rise with GDP and deficit is fixed at base year levels. After baseline, government expenditures fixed to baseline levels—eases welfare comparison.
- Investment expenditures—Basic aim is to adjust household savings so that return to capital is more or less unchanged over time. This requires trial and error. After baseline, household saving rates are held fixed and investment targets are endogenous.
- Foreign savings. No default assumptions, however, should not be allowed to grow outside some thresholds, e.g. 3% of GDP.
- Fiscal and other policies. No default, should implement those that are planned—for example trade policy changes (new FTAs), nationally determined commitments (NDCs), i.e. Paris Agreement, others...


Socio-economic challenges for mitigation
SSP5
(Mitigation challenges dominiate)
Fossil-fueled Development
Taking the Highway
SSP3
(High challenges)
Regional Rivalry
A Rocky Road
SSP2
(Intermediate challenges)
Middle of the Road
SSP1
(Low challenges)
Sustainability
Taking the Green Road
SSP4
(Adaptation challenges dominate)
Inequality
A Road Divided
Socio-economic challenges for adaptation

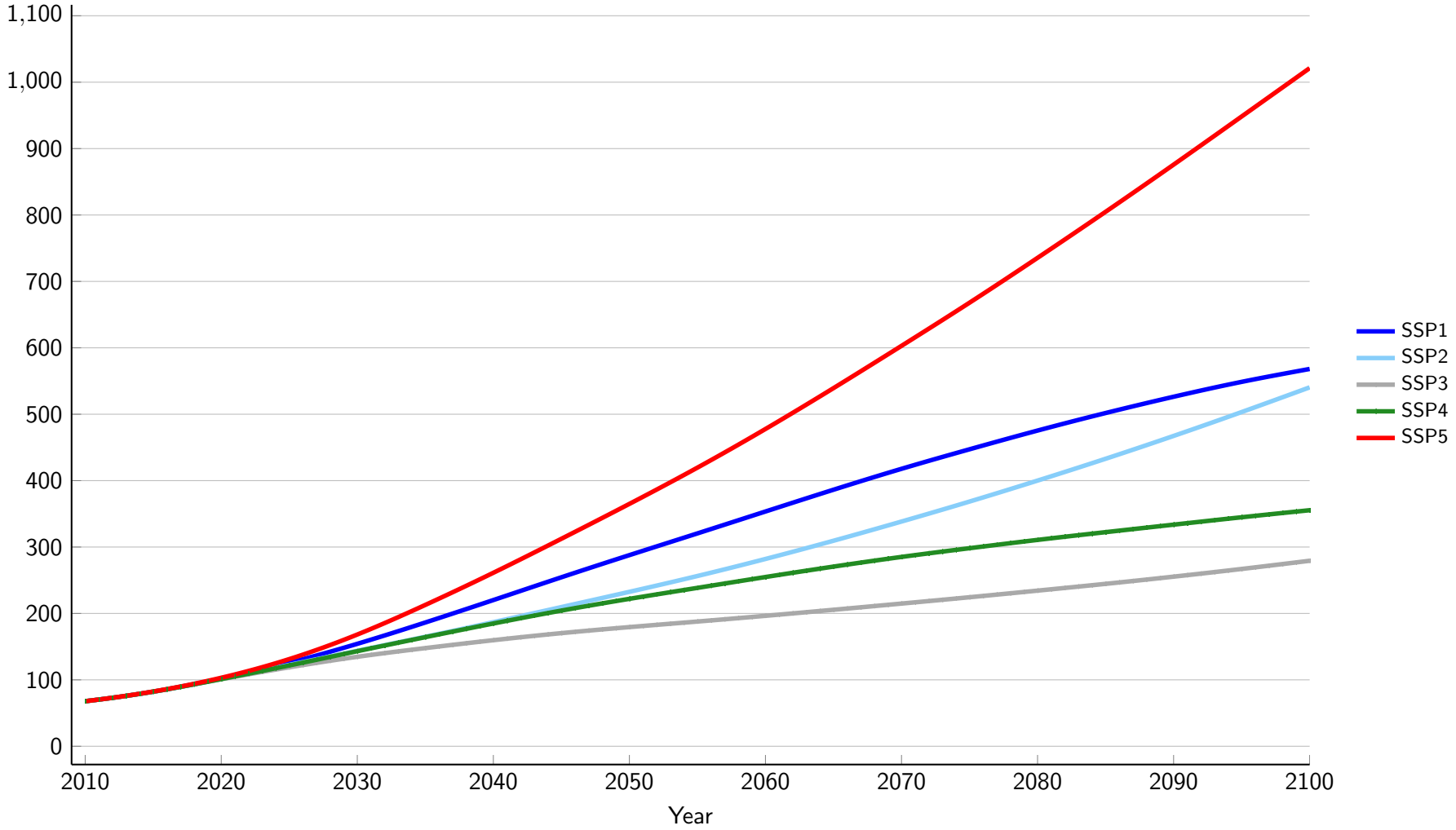
Quantification

- Demographics—IIASA based (Wittgenstein Center). All 5 SSPs, population by 5 year age cohorts ($0-4$, $5-9$, ..., 95-99, 100+), by gender and education (none, primary, secondary and tertiary)
- GDP—three projections from 2010/2100, 2 at country level (IIASA and OECD), one at 32-region level (PIK). Projections for all 5 SSPs harmonized to the same IIASA-based demographic projections.
- Center provides GTAP conformable SSP database, gap-filled and annualized and also includes various UN Population Division demographic projections, including 2015 and 2017 revisions.
- Model based indicators are available for non-harmonized indicators—energy mix, greenhouse gas emissions, etc. from the IIASA-based SSP database.

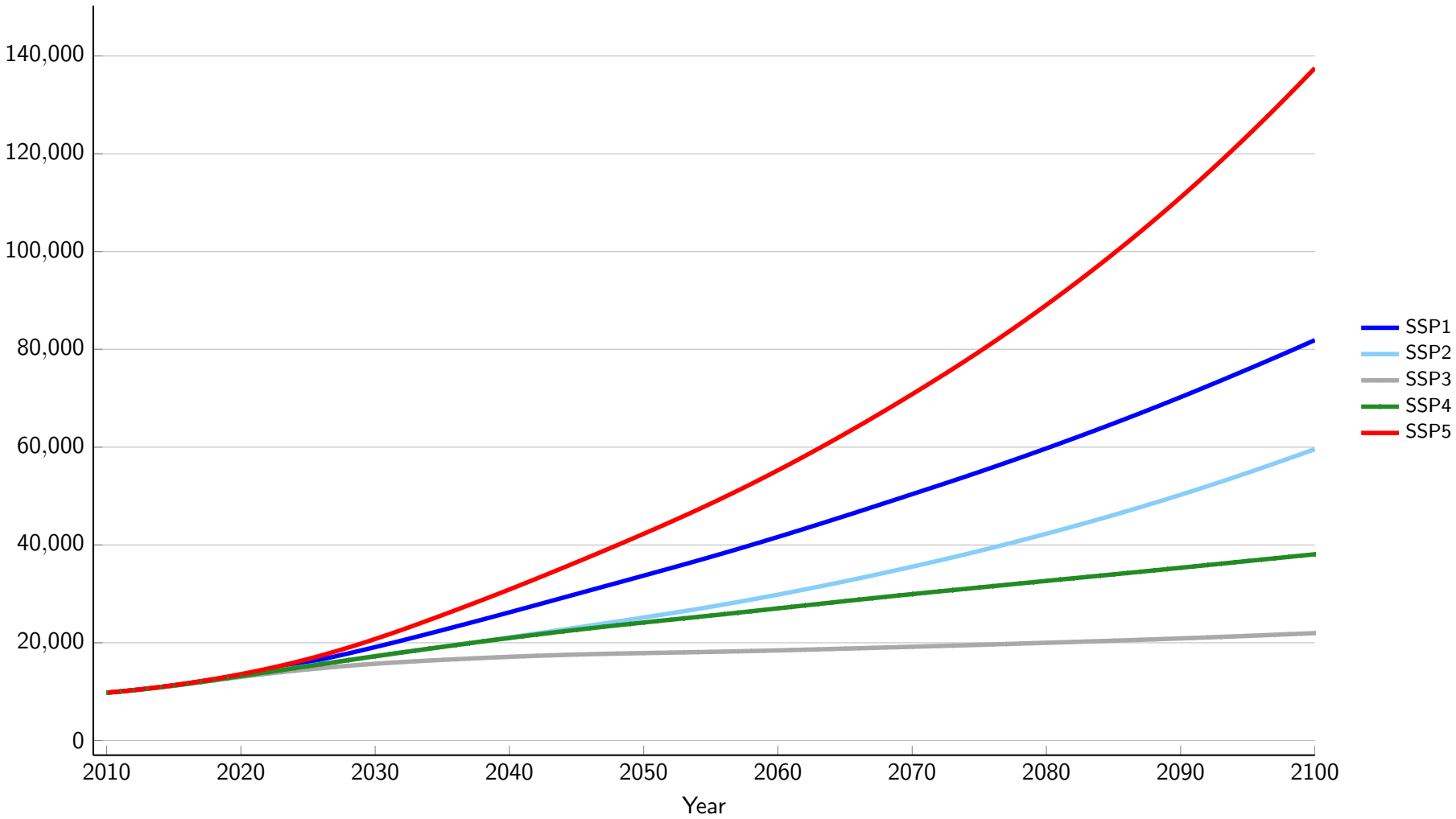
World Population (billion): Backward and Forward



World GDP ($2005 trillion)



World GDP per capita ($2005)



Thank you!