Potsdam Institute for
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P I K

Direct Climate Damage on Capital

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Research Domain III – Transformation Pathways
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Introduction

Traditional IAMs apply aggregate damage functions linking temperature increases to GDP losses. This "top-down" approach obscures transmission mechanisms and constrains adaptation policy analysis (Piontek et al. 2021). We develop a "bottom-up" framework explicitly modeling climate damage to *capital stocks* across sectors and regions within the Multi-Sector Growth (MSG) model, integrated with REMIND energy supply dynamics. This approach separates potential capital stock from production capacity, enabling representation of damage, depreciation, and rebuilding dynamics.

Methodology

Based on (Otto et al. 2022), we decompose the capital stock as

$$K_{r,s}(t) = \xi_{r,s}(t) \cdot K^p_{r,s}(t) \tag{1}$$

where $\xi_{r,s}(t) \in [0,1]$ is the production capacity factor (undamaged fraction) and $K^p_{r,s}(t)$ is potential capital. Total investment splits: $I_{r,s}(t) = I^p_{r,s}(t) + I^\xi_{r,s}(t)$ between new capital and rebuilding.

Continuous-Time Foundations. Capital accumulation with climate damage:

$$\dot{K}_{r,s}(t) = I_{r,s}(t) - (\delta_{r,s} + \delta^D_{r,s}(t))K_{r,s}(t) \tag{2}$$

where $\delta_{r,s}$ is standard depreciation and $\delta^D_{r,s}(t)$ is climate damage rate. Potential capital evolves as:

$$\dot{K}^p_{r,s}(t) = I^p_{r,s}(t) - \delta_{r,s}K^p_{r,s}(t) \tag{3}$$

Discrete-Time System. Integrating over time step Δt yields:

$$K^p_{r,s,t+\Delta t} = e^{-\delta_{r,s}\Delta t}K^p_{r,s,t} + I^p_{r,s,t}\frac{1-e^{-\delta_{r,s}\Delta t}}{\delta_{r,s}} \tag{4}$$

$$\xi_{r,s,t+\Delta t} = e^{-(\delta^D_{r,s,t}+\delta_{r,s})\Delta t}\frac{K^p_{r,s,t}}{K^p_{r,s,t+\Delta t}}\xi_{r,s,t} + \frac{I^\xi_{r,s,t}+I^p_{r,s,t}}{K^p_{r,s,t+\Delta t}}\frac{1-e^{-(\delta^D_{r,s,t}+\delta_{r,s})\Delta t}}{\delta^D_{r,s,t}+\delta_{r,s}} \tag{5}$$

$$I^\xi_{r,s,t} \leq \min\left[(1-\xi_{r,s,t})K^p_{r,s,t}, f^{max}_{r,s,t}Y_{r,s,t}, I_{r,s,t}\right] \tag{6}$$

where $f^{max}_{r,s,t}$ limits reconstruction capacity (here as fraction of output).

Notes:

- *Capital services specification:* Flexible specification of rebuilding incentives independently from capital stock dynamics: the output depends only on total investment $I = I^p + I^\xi$ (see steady state & Fig. 2). Production uses capital services $S_k = \xi^{1.05} \cdot K^p$, incentivizing rebuilding
- *Exogenous drivers:* Technological progress and population are exogenous. Capital accumulation is the only endogenous growth source
- *Steady state:* $K^p_{r,s} = I^p_{r,s}/\delta_{r,s}$, $\xi_{r,s} = [\delta_{r,s}/(\delta_{r,s}+\delta^D_{r,s})] \cdot [(I^p_{r,s}+I^\xi_{r,s})/I^p_{r,s}]$, and $K_{r,s} = I_{r,s}/(\delta^D_{r,s}+\delta_{r,s})$
- Simulations: India, SSP2 socioeconomic path, RCP2.6 climate pathway (when relevant)

Results

Capital damage implementations: shock and damage functions (Figure 1). Top panels show consumption and output impact ratios from capital damage. Bottom-left panel contrasts the discrete shock (50% capital loss in 2060) with the damage function (∼2% temperature-dependent loss, modeled with perfect foresight). Bottom-right panel shows capital trajectories: for the shock scenario, perfect foresight agents preemptively reduce accumulation before the shock, while myopic agents follow the baseline then respond reactively.

- Capital destruction leads to very persistent loss of output and consumption
- Consumption loss is larger than output loss, as economies divert resources toward rebuilding
- High vulnerability: Climate hazards destroying around 2% of productive capital annually (mean) lead to a relatively large drop in consumption and output (around 5% from 2070 onwards for both)
- High resilience: an unanticipated one-time 50% destruction of capital stock leads to a drop in consumption and output of "only" around 20 % and 16 % respectively

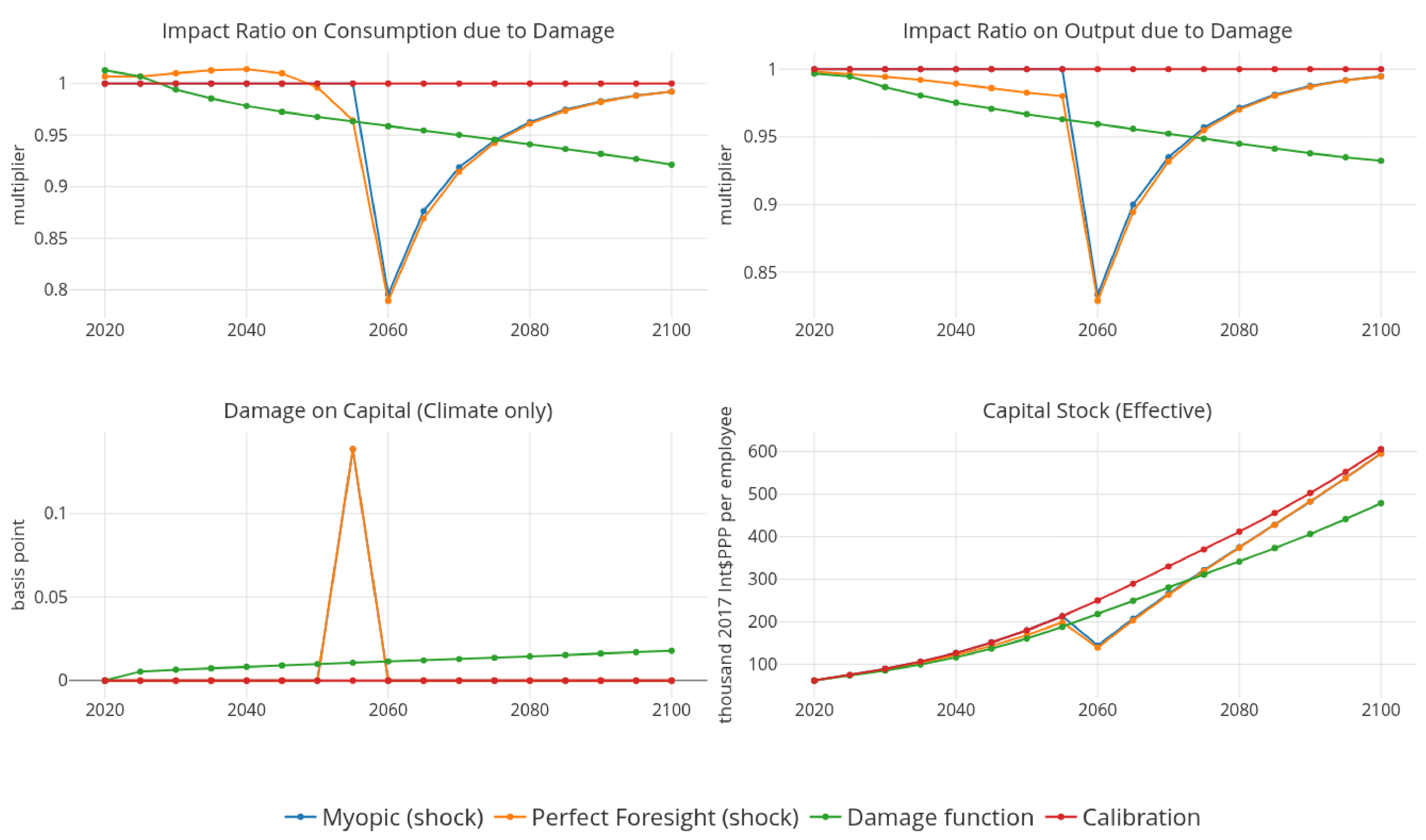

Figure 1: Impact ratios and capital dynamics under shock-based vs. function-based damage

Persistence and Reconstruction Constraints (Figure 2). Recovery from capital shocks exhibits substantial persistence, with consumption and output half-life (time for shock impact to decay to 50% of initial value) around 8 years. This persistence is only modestly affected by:

- Reconstruction capacity constraints (Figure 2: 5-100% of sectoral investment)
- Discount rate of the optimizer (when recalibrated)
- Magnitude of the shock
- Utility preferences for reconstructions

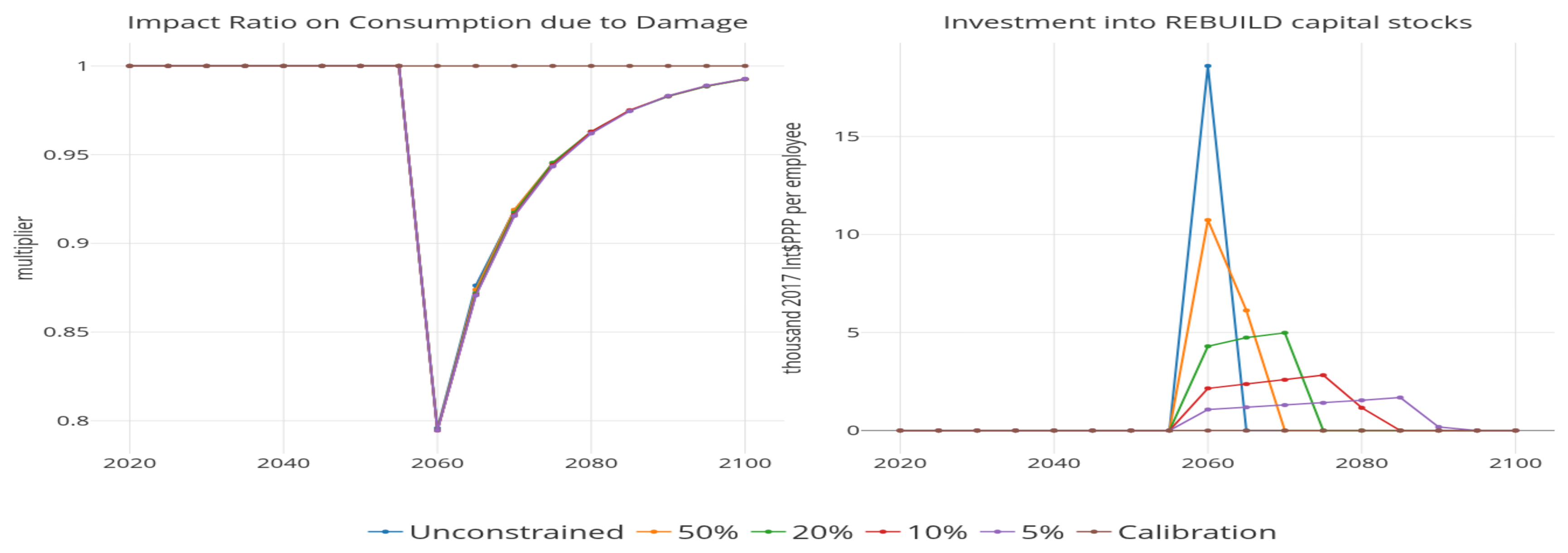

Figure 2: Consumption and rebuilding under varying reconstruction capacity constraints

Stochastic Damage and Agent Expectations (Figures 3 & 4). Monte Carlo simulations (200 runs, exponential damage distribution, mean 3%).

- As for Fig. 1, perfect foresight agents exhibit precautionary capital accumulation, while myopic agents respond reactively to realized shocks
- Mean outcomes from stochastic damage simulations closely match deterministic scenarios using mean damage rates, for both myopic and perfect foresight agents (see Fig. 3)
- Skewness in the damage distribution propagates partially to consumption and output losses (Fig. 4), with substantial outcome variation across damage realizations (Q1-Q3 on Fig. 3 and Fig. 4)
- Foresight specification has a noticeable impact on output but marginal impact on consumption

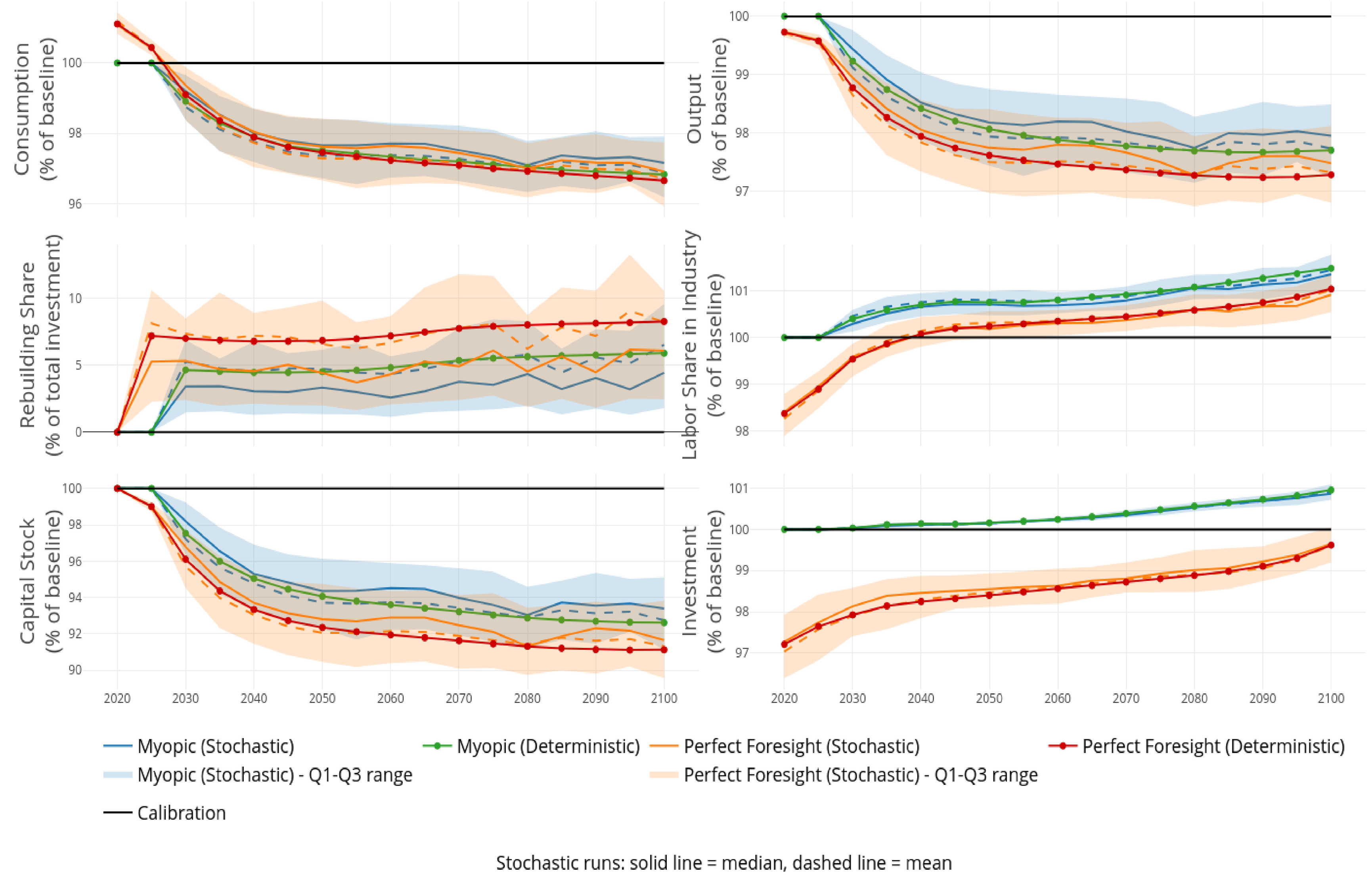

Figure 3: Myopic versus perfect foresight under stochastic and deterministic damage scenarios (India)

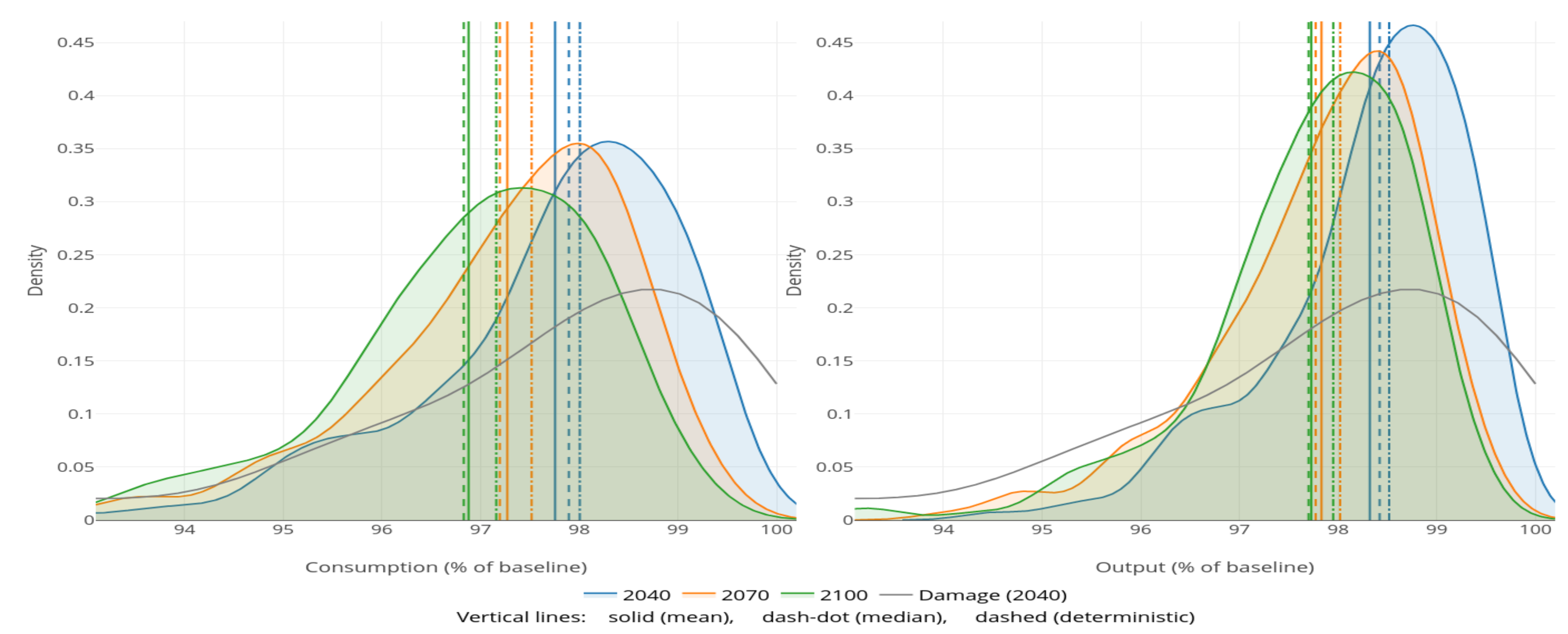

Figure 4: Myopic foresight stochastic distributions for consumption and output (India)

Next Steps

Reconstruction. Test multiple rebuilding behaviors and reconstruction capacity constraints.

Multi-Channel Damage Functions. Integrate empirical estimates (e.g., from Mandel et al. 2025) to develop damage functions with multiple transmission channels (cyclones, floods, heatwaves, etc.).

Sectoral Characteristics. Refine sector-specific parameters (depreciation rates, vulnerability patterns, and production elasticities) to better capture heterogeneous climate impacts and responses.

Trade Spillovers. Incorporate international transmissions through trade networks, examining how localized capital destruction propagates across borders through supply and demand disruptions.

Double-Crunch Dynamics. Investigate feedback between capital destruction and capital costs—how large-scale damage events tighten reconstruction capacity and raise financing costs.

References

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