ADAPTATION TO CLIMATE CHANGE AND ECONOMIC GROWTH IN DEVELOPING COUNTRIES

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STYLIZED FACTS

Developing countries, particularly in sub-Saharan Africa, are highly vulnerable to climate change:

- Geographic location
- High sensitivity (e.g. share of GDP in agriculture)
- Low adaptive capacity (e.g. finance, institutions, information)

Even if (and that’s a BIG “if”) we get effective mitigation, climate change will occur due to long residence time of atmospheric CO$_2$.

How should developing countries adapt to climate change?

- “Development is the best form of adaptation” – i.e. invest as usual in productive capital
- “Development is contingent on adaptation” – i.e. invest to ‘climate-proof’ productive capital

Towards adjudicating between these positions, we:

- Construct a fully dynamic, easy to interpret, analytical model of adaptation as an investment problem at the macro level
- Apply the model empirically to Sub-Saharan Africa, with extensive sensitivity analysis

We find that in most contingencies it will be optimal to grow the stock of adaptive capital rapidly over the next 50 years.
MODEL SETUP

Modified Ramsey-Cass-Koopmans growth model (cf. DICE)

Two capital stocks

- ‘Vulnerable capital’ – productive, but damaged by CC
- ‘Adaptive capital’ – unproductive in the absence of CC, but reduces CC damages to vulnerable capital output

Two controls

- Consumption/investment in vulnerable capital
- Investment in adaptive capital

Exogenous temperature change (small developing country/region), population and TFP

Convex cost of investment in adaptive capital
Captures barriers to adapting quickly such as planning costs, policy delays and corruption
MODEL SETUP II

Social Planner’s Objective:
\[
\max_{c(t), I(t)} \int_0^T L(t)U(c(t))e^{-\rho t} dt
\]

Vulnerable capital \(K_V\):

\[
\dot{K}_V = A(t)D(K_A, X(t))F(K_V, L(t)) - \delta_V K_V - cL(t) - Q(I)
\]

Adaptive capital \(K_A\):

\[
\dot{K}_A = I - \delta_A K_A
\]

TFP  \hspace{1cm} GDP  \hspace{1cm} Depreciation  \hspace{1cm} Adaptation costs

Damages = D(Adaptive capital, Exogenous Temperature)  \hspace{1cm} Consumption

Adaptive investment  \hspace{1cm} Depreciation
INTERACTION BETWEEN ADAPTIVE CAPITAL AND CLIMATE CHANGE

All interactions are captured by the modified damage multiplier:

\[ D(K_A, X) : \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow [0, 1] \]

We assume:

1. \( D \) is decreasing in \( X \) (climate change is ‘bad’).
2. \( K_A \) unproductive in the absence of climate change (i.e. \( D(K_A, 0) = 1 \))
3. \( D \) is increasing and concave in \( K_A \).
4. “Productivity” of the marginal unit of \( K_A \) is increasing in \( X \), i.e. \( \frac{\partial^2 D}{\partial K_A \partial X} > 0 \)
**MODEL EQUATIONS**

**State equations:**

\[ \dot{K}_V = A(t)D(K_A, X(t))F(K_V, L(t)) - \delta_V K_V - cL(t) - Q(I) \]
\[ \dot{K}_A = I - \delta_A K_A \]

**Euler equations** (follow from Maximum principle):

\[ \dot{c} = \frac{c}{\eta(c)} [A(t)D(K_A, X(t))F_{K_V} - \delta_V - \rho] \] **Ramsey eq**

\[ \dot{I} = \frac{Q'(I)}{Q''(I)} [A(t)D(K_A, X(t))F_{K_V} - \delta_V + \delta_A] - \frac{1}{Q''(I)} A(t)D_a(K_A, X(t))F(K_V, L(t)) \]

**Capital adjustment eq**: Make marginal products of \( K_A \) & \( K_V \) more equal, but not “too fast”.

**Terminal conditions**: Pick values for \( K_V(T), K_A(T) \)

4 dimensional coupled nonlinear system.
We are interested in the **transient** (not steady state) regime.
DEPENDENCE OF OPTIMAL INVESTMENT RULE ON CAPITAL (NO ADJUSTMENT COSTS)

For simplicity, assume:
• \( Q(l) = l \), i.e. no adjustment costs.
• Depreciation rates of two types of capital are equal.

\[
I = R_X(K_V, K_A, X) \dot{X} + R_V(K_V, K_A, X) \dot{K}_V + \delta_A K_A
\]

Remark: If \( \dot{X} > 0 \) and \( \dot{K}_V > 0 \), then \( I > 0 \) (since \( R_V > 0 \) and \( R_X > 0 \))

Proposition:

\( R_X \) is an increasing (decreasing) function of \( K_V \) when \( \epsilon_{a,a} < \epsilon_{X,a} (\epsilon_{a,a} > \epsilon_{X,a}) \)

\( R_V \) is decreasing in \( K_V \)

Implications:
• The strong “adapt through development” position is probably not optimal.
• Richer economies respond proportionately less to changes in \( K_V \) but may respond proportionately \( more \) to changes in \( X \) if the damage reduction effect of a marginal unit of adaptive capital outweighs its effect on the returns to adaptive investment.
FULL DYNAMIC SIMULATIONS FOR SUB-SAHARAN AFRICA

Why Sub-Saharan Africa?

- Small emitter of carbon: reasonable to assume climate change is exogenous
- Highly vulnerable to climate change

Close the model:

- Choose sensible functional forms for: $D(K_A, X)$, $F(K_V, L)$, $Q(I)$ and $U(c)$
- Calibrate model parameters based on IAM literature

Note calibration takes into account:

1. Flow adaptation
2. Relationship between income and damages
BASE CASE: COSTS & BENEFITS

Damages as % GDP

Investment Costs as % GDP

Same order of magnitude as AD-WITCH model.

WELFARE VS. CLIMATE SENSITIVITY
WITH AND WITHOUT ADAPTATION

BASE CASE: RATIO OF VULNERABLE TO ADAPTIVE CAPITAL AS FUNCTION OF TIME (BOTH CHOSEN OPTIMALLY)
ROBUSTNESS OF CAPITAL RATIO TRAJECTORY

The qualitative ‘U-shaped’ dependence of the capital ratio on time is robust to plausible changes in the values of:

1. Adjustment cost parameter
2. Rate of growth of TFP
3. Pure rate of time preference
4. Elasticity of Marginal Utility
5. Climate sensitivity and emissions pathway

It is NOT robust to changes in:
1. An ‘Adaptation Effectiveness’ parameter
2. Initial stock of adaptive capital
SENSITIVITY TO ADJUSTMENT COSTS: DIFFERENCE IN GROWTH RATES OF VULNERABLE AND ADAPTIVE CAPITAL VS. ADJUSTMENT COST PARAMETER

First 50 years

Second 50 years

CAPITAL RATIO FOR LOW ADAPTATION EFFECTIVENESS

SENSITIVITY TO ADAPTATION EFFECTIVENESS
WELFARE VS. ADAPTATION EFFECTIVENESS PARAMETER

Stationary equivalent consumption (2005 USD)

BAU
2CO₂
1.5CO₂

CONCLUSIONS

Developed a simple, transparent model for informing policy discussions.

In most plausible cases, we find that it is optimal to grow the stock of adaptive capital rapidly over the next 50 years.

This conclusion is robust to changes in the values of all model parameters, except:

• i) Effectiveness of adaptation
• ii) Initial stock of adaptive capital (which is probably very low)

These are the parameters we should focus on pinning down empirically.

Our analytics show that simple ad hoc prescriptions are almost certainly wrong: Everything depends on empirical details.

Caveats: Uncertainty & Learning, Thresholds, Extreme Events, Institutions, etc., etc.
ADDITIONAL MATERIALS
## MODEL PARAMETERS – BASE CASE CALIBRATION

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Interpretation</th>
<th>Base case value</th>
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<tbody>
<tr>
<td>$\gamma$</td>
<td>Capital share of production</td>
<td>0.3</td>
</tr>
<tr>
<td>$\alpha_1, \alpha_2$</td>
<td>Gross damage multiplier parameters</td>
<td>$(2.22 \times 10^{-14}, 0.75 \times 10^{-1})$</td>
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<tr>
<td>$\beta_1, \beta_2^*$</td>
<td>Residual damage multiplier parameters (effectiveness of adaptation)</td>
<td>$(0.32 \times 10^{-2}, 0.17)$</td>
</tr>
<tr>
<td>$\delta_A, \delta_V$</td>
<td>Capital depreciation rates</td>
<td>10%/year</td>
</tr>
<tr>
<td>$q^*$</td>
<td>Cost of adjustment parameter</td>
<td>$9.70 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\eta^*$</td>
<td>Elasticity of marginal utility</td>
<td>2</td>
</tr>
<tr>
<td>$\rho^*$</td>
<td>Rate of pure time preference</td>
<td>1.5%/year</td>
</tr>
<tr>
<td>$L(t)$</td>
<td>Population</td>
<td>From RICE</td>
</tr>
<tr>
<td>$A(t)^*$</td>
<td>Total factor productivity</td>
<td>From RICE</td>
</tr>
<tr>
<td>$X(t)^*$</td>
<td>Temperature change</td>
<td>From DICE</td>
</tr>
<tr>
<td>$K_V(0)/L(0)$</td>
<td>Initial stock of vulnerable capital per capita</td>
<td>$2796$</td>
</tr>
<tr>
<td>$K_A(0)/L(0)^*$</td>
<td>Initial stock of adaptive capital per capita</td>
<td>$0.50$</td>
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GLOBAL TEMPERATURE TRAJECTORIES

S = 1.5°C
S = 3°C
S = 4.5°C
S = 6°C

BASE CASE RESULTS: OPTIMAL CONTROLS

Consumption per capita vs. time

Adaptive investment per capita vs. time

SENSITIVITY TO ADAPTATION EFFECTIVENESS: \( (G_V - G_A) \)
SENSITIVITY TO DISCOUNT RATE: CAPITAL RATIO

![Graphs showing sensitivity of capital ratio to discount rate]