ADAPTATION TO CLIMATE CHANGE AND ECONOMIC GROWTH IN DEVELOPING COUNTRIES

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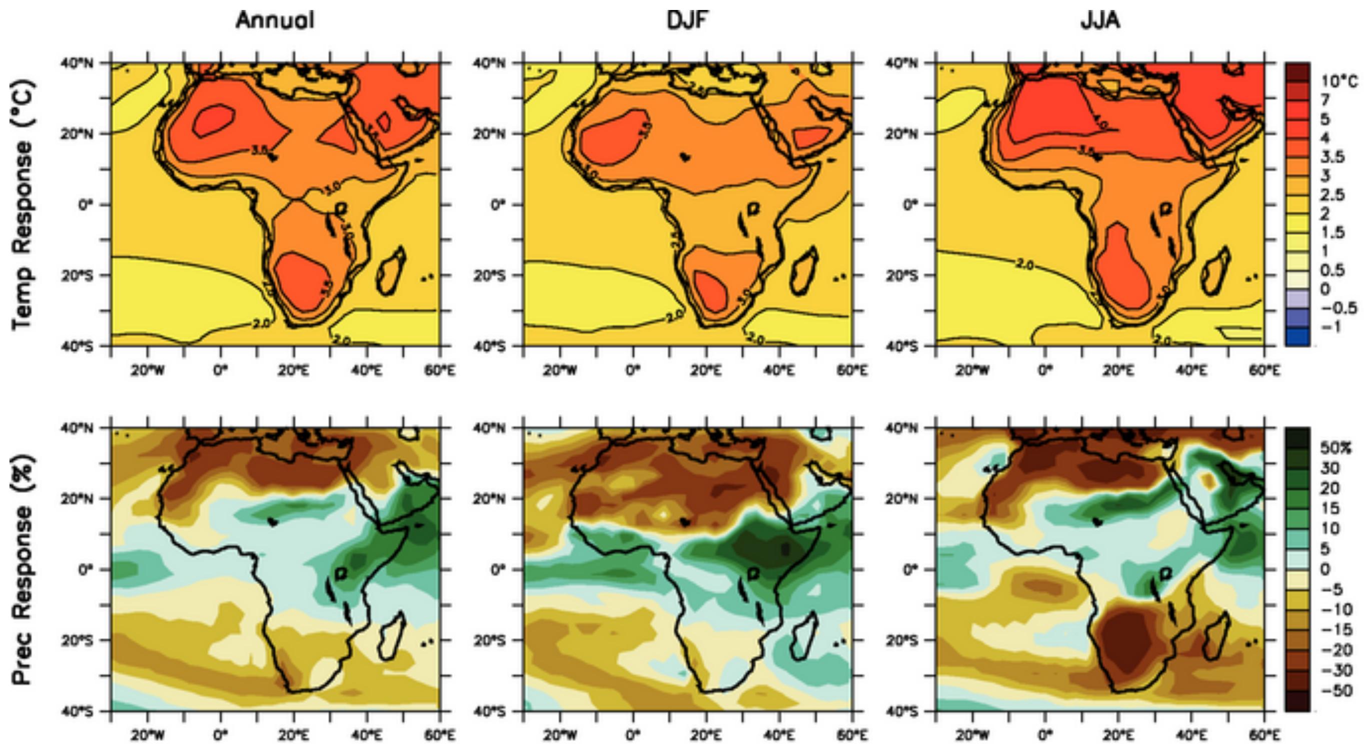
STYLIZED FACTS

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.

THIS PAPER IN A NUTSHELL

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:

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

GDP: $F(K_V, L(t))$

Depreciation: $\delta_V K_V$

Adaptation costs: $Q(I)$

TFP: $A(t)$

Damages = D(Adaptive capital, Exogenous Temperature)

Consumption: $cL(t)$

Adaptive capital K_A:

$$\dot{K}_A = I - \delta_A K_A$$

Adaptive investment: I

Depreciation: $\delta_A K_A$

INTERACTION BETWEEN ADAPTIVE CAPITAL AND CLIMATE CHANGE

All interactions are captured by the modified damage multiplier:

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

Adaptive capital Temperature

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):

$$\dot{c} = \frac{c}{\eta(c)}\left[A(t)D(K_A, X(t))F_{K_V} - \delta_V - \rho\right]$$

← Ramsey eq^n

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

↑

Capital adjustment eq^n: 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*** (<u>not</u> steady state) regime

DEPENDENCE OF OPTIMAL INVESTMENT RULE ON CAPITAL (NO ADJUSTMENT COSTS)

For simplicity, assume:

- *Q(I)* = *I*, 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:

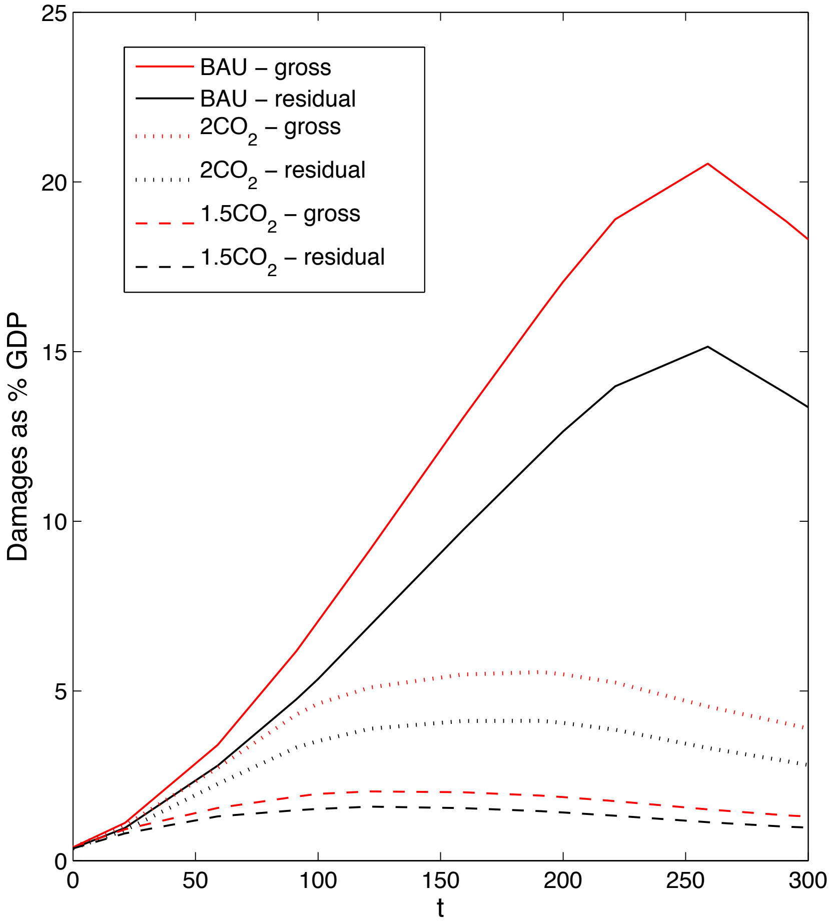
- Choose sensible functional forms for: $D(K_A,X)$, $F(K_V,L)$, $Q(I)$ and $U(c)$
- Calibrate model parameters based on IAM literature

Note calibration takes into account:

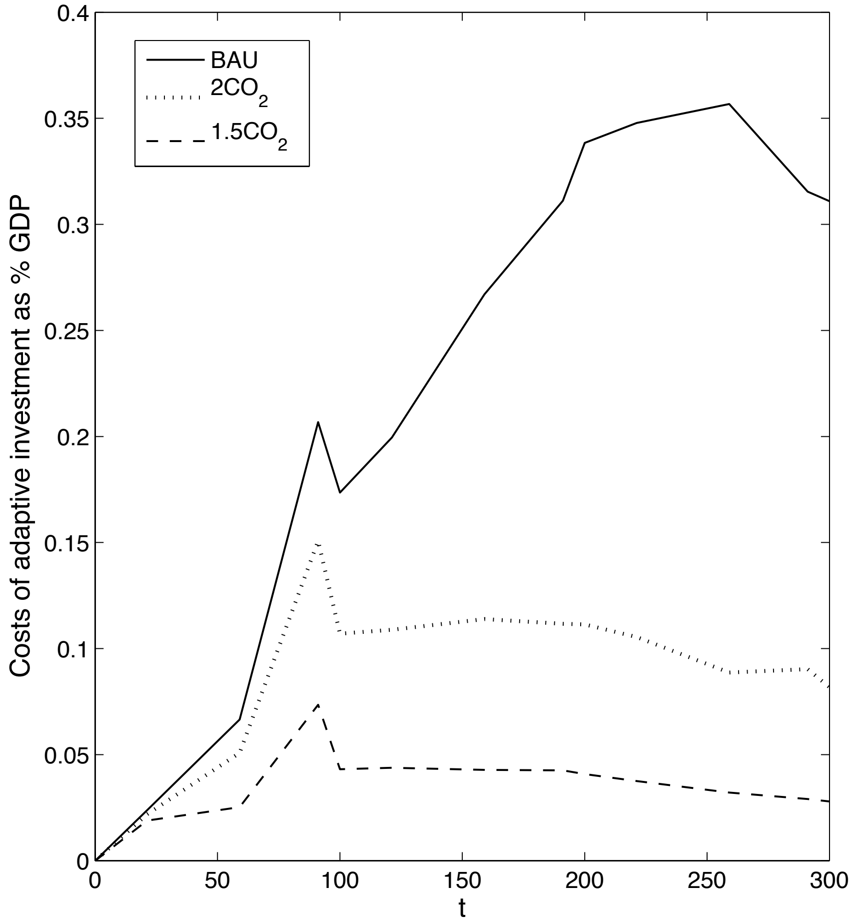
1. Flow adaptation
2. Relationship between income and damages

BASE CASE : COSTS & BENEFITS

Damages as % GDP



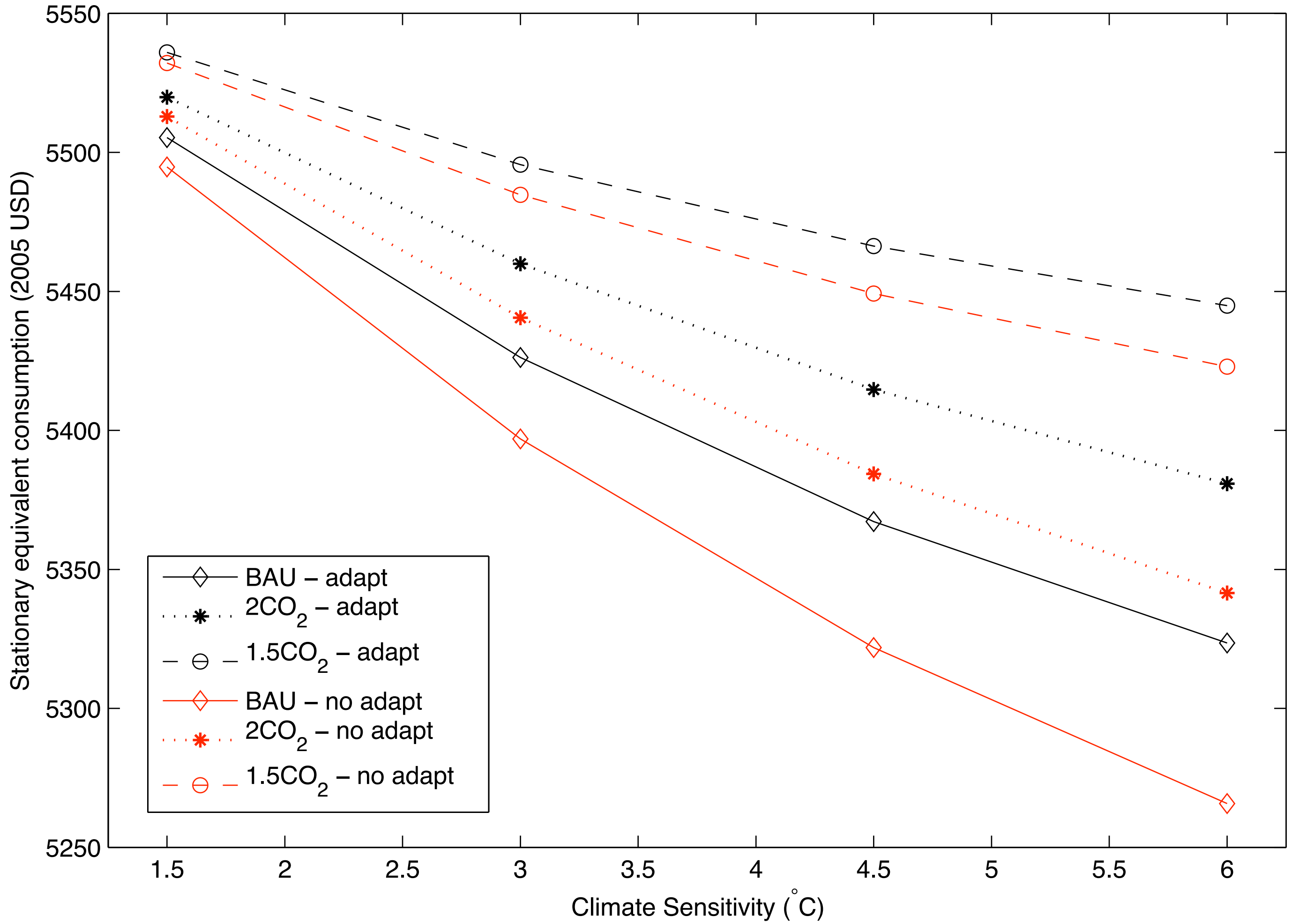
Investment Costs as % GDP



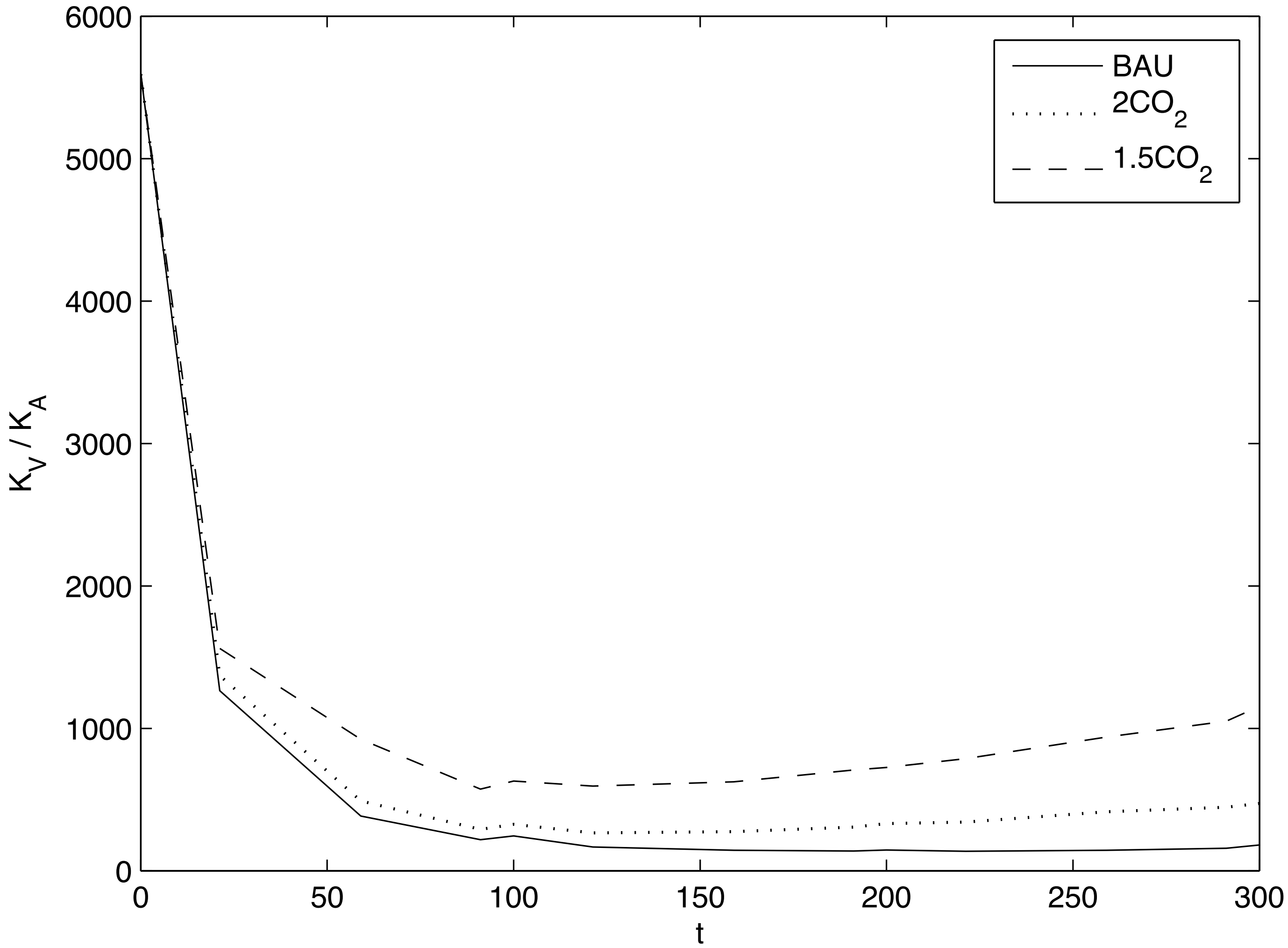
Same order of magnitude as AD-WITCH model.

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:

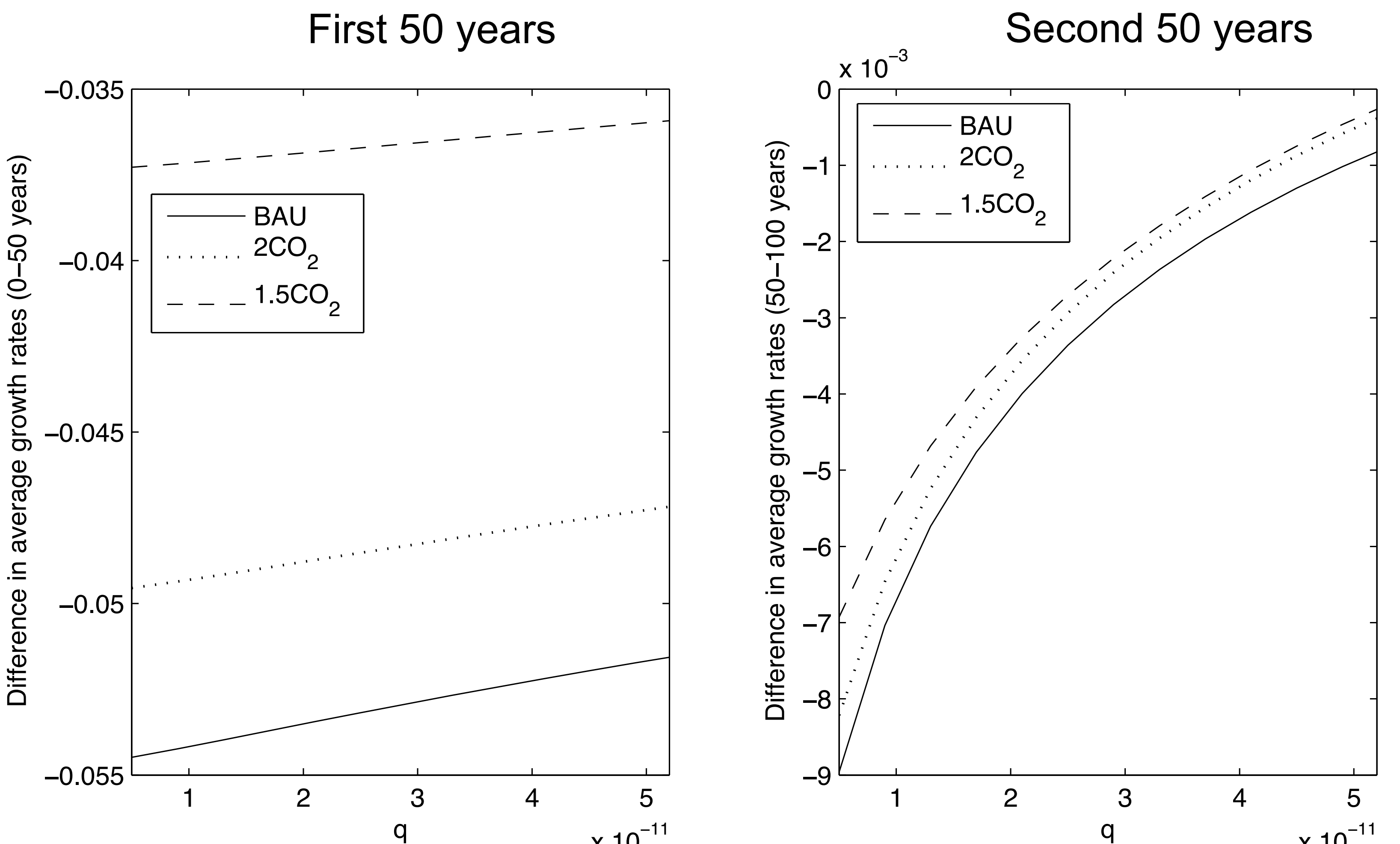
1. **Adjustment cost parameter**
2. **Rate of growth of TFP**
3. **Pure rate of time preference**
4. **Elasticity of Marginal Utility**
5. **Climate sensitivity and emissions pathway**

It is NOT robust to changes in:

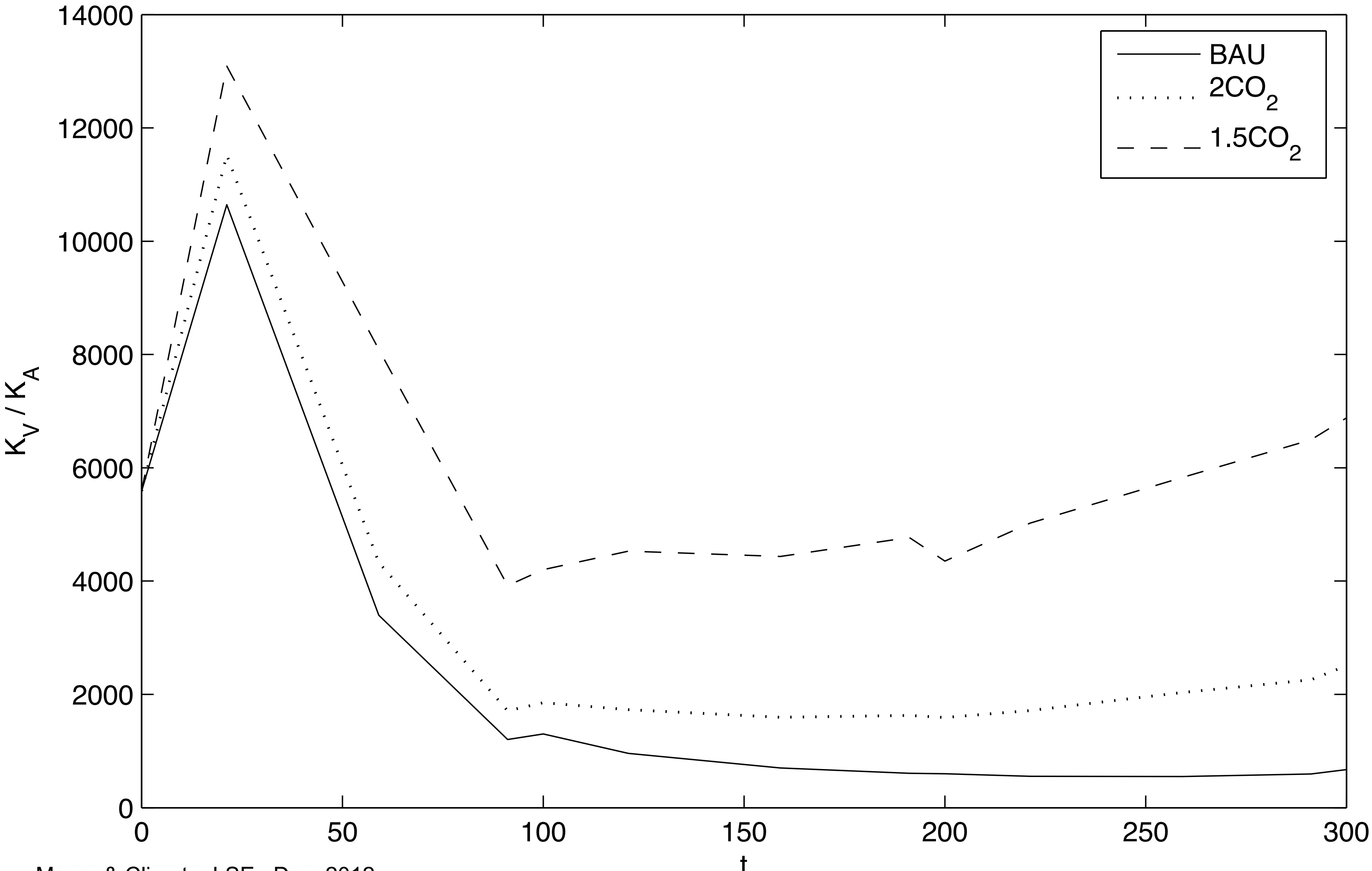
1. **An 'Adaptation Effectiveness' parameter**
2. **Initial stock of adaptive capital**

SENSITIVITY TO ADJUSTMENT COSTS:

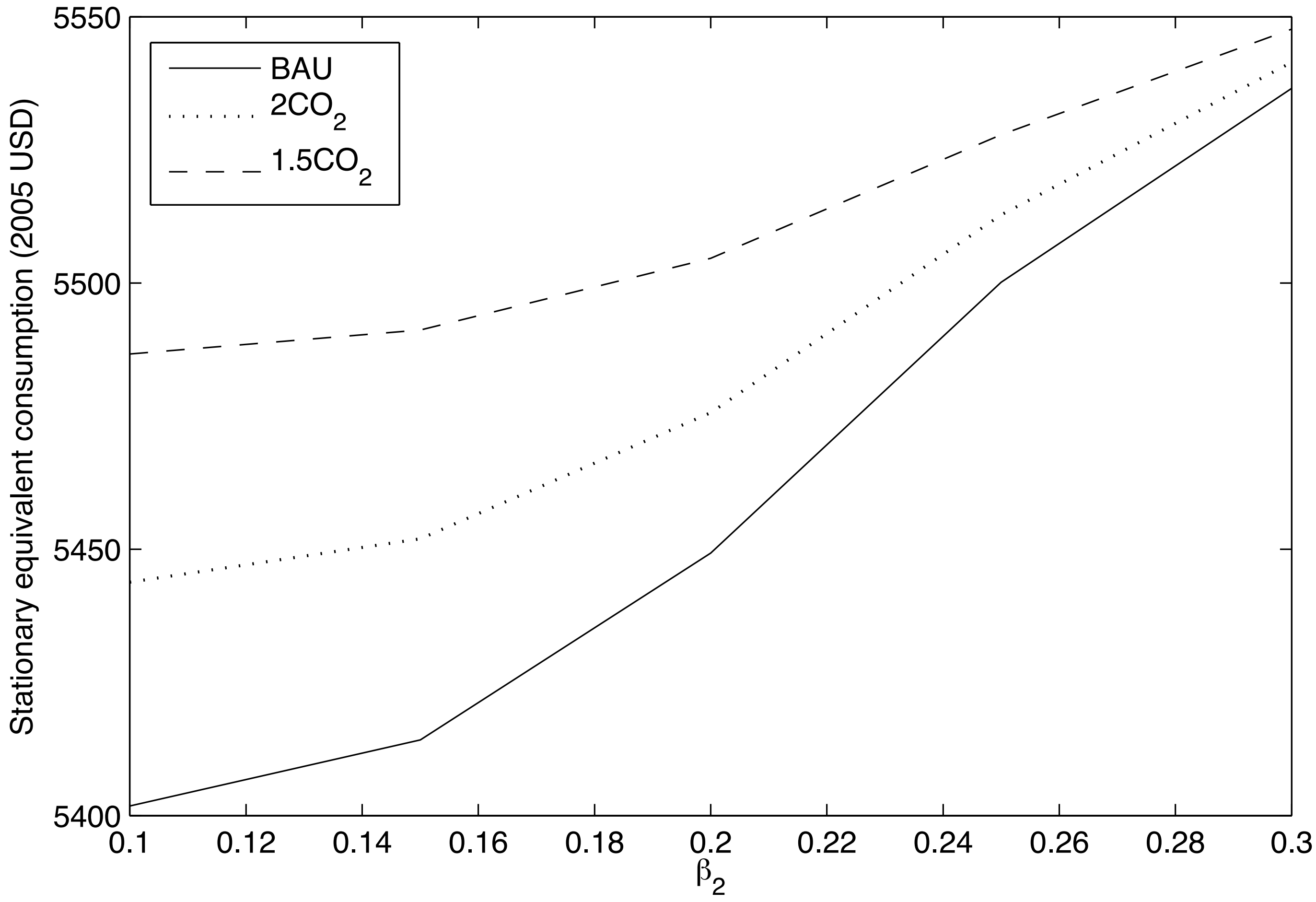
DIFFERENCE IN GROWTH RATES OF VULNERABLE AND ADAPTIVE CAPITAL VS. ADJUSTMENT COST PARAMETER



CAPITAL RATIO FOR LOW ADAPTATION EFFECTIVENESS



SENSITIVITY TO ADAPTATION EFFECTIVENESS
WELFARE VS. ADAPTATION EFFECTIVENESS PARAMETER



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.

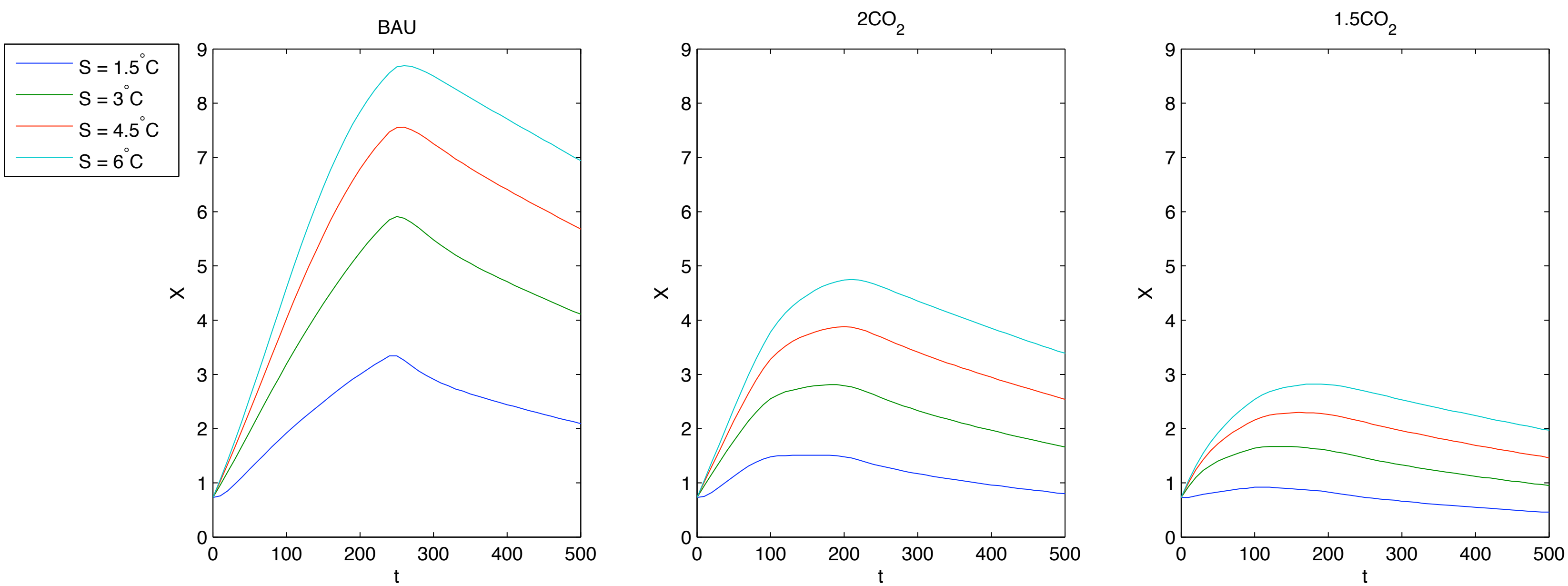
Caveats: Uncertainty & Learning, Thresholds, Extreme Events, Institutions, etc., etc.

ADDITIONAL MATERIALS

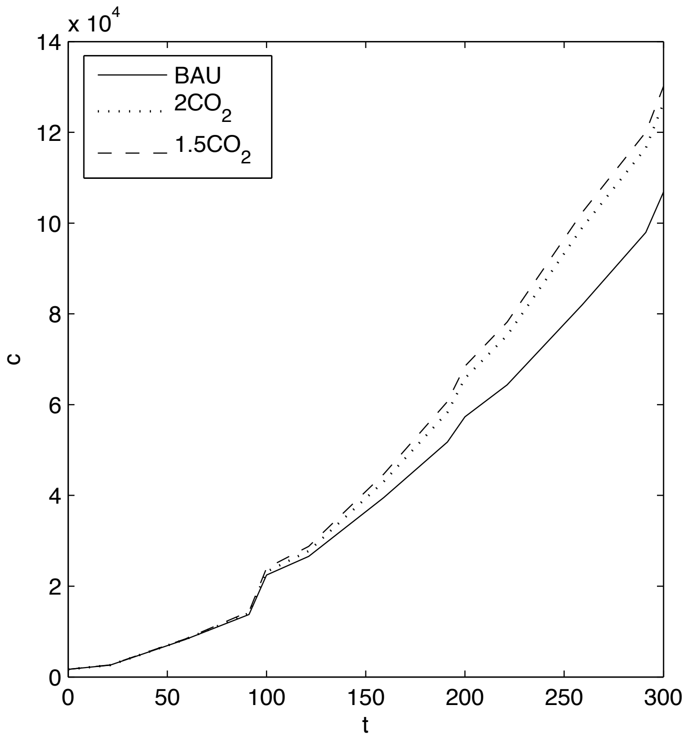
MODEL PARAMETERS – BASE CASE CALIBRATION

Parameter	Interpretation	Base case value
γ	Capital share of production	0.3
α_1, α_2	Gross damage multiplier parameters	$(2.22 \times 10^{-14}, 0.75 \times 10^{-}$
β_1, β_2^*	Residual damage multiplier parameters (effectiveness of adaptation)	$(0.32 \times 10^{-2}, 0.17)$
δ_A, δ_V	Capital depreciation rates	10%/year
q^*	Cost of adjustment parameter	9.70×10^{-12}
η^*	Elasticity of marginal utility	2
ρ^*	Rate of pure time preference	1.5%/year
$L(t)$	Population	From RICE
$A(t)^*$	Total factor productivity	From RICE
$X(t)^*$	Temperature change	From DICE
$K_V(0)/L(0)$	Initial stock of vulnerable capital per capita	$2796
$K_A(0)/L(0)^*$	Initial stock of adaptive capital per capita	$0.50

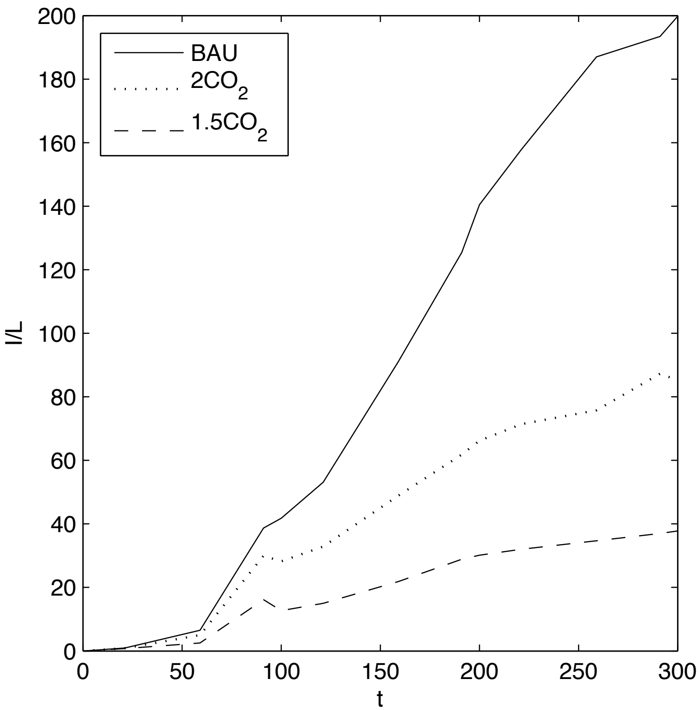
GLOBAL TEMPERATURE TRAJECTORIES



BASE CASE RESULTS: OPTIMAL CONTROLS

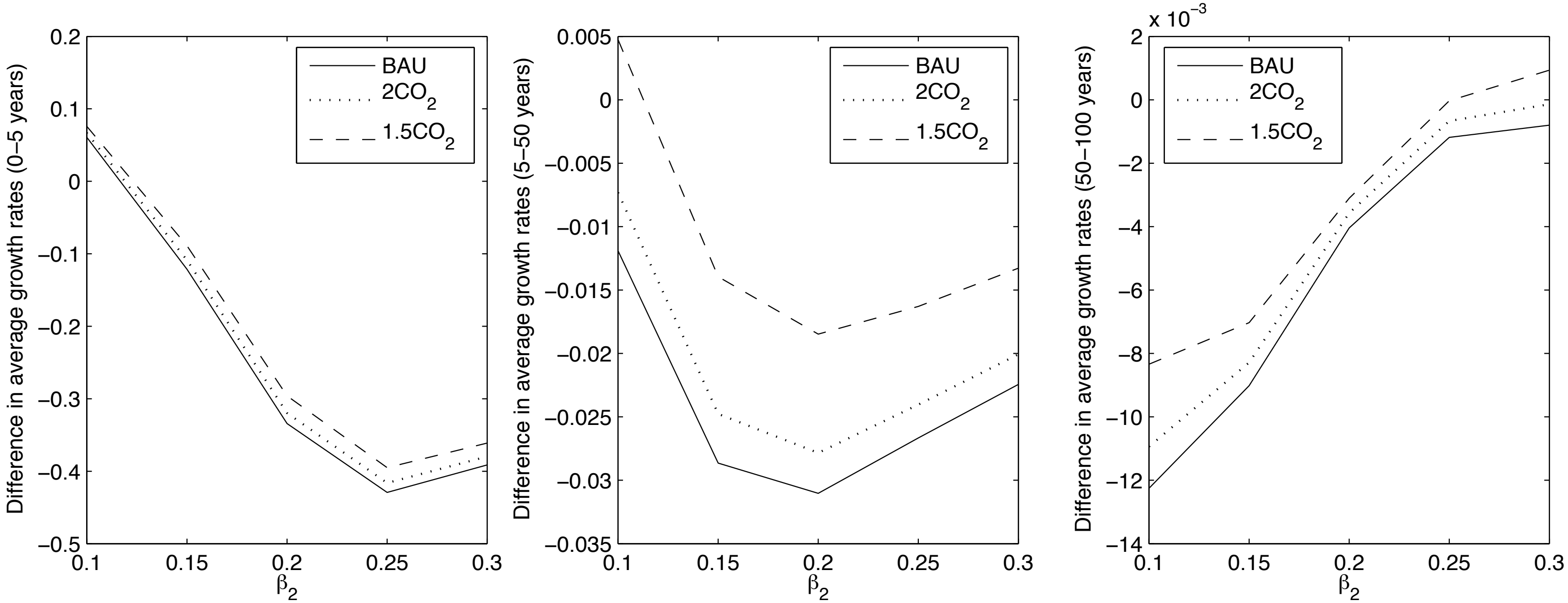


Consumption per capita vs. time



Adaptive investment per capita vs. time

SENSITIVITY TO ADAPTATION EFFECTIVENESS: $(G_V - G_A)$



SENSITIVITY TO DISCOUNT RATE: CAPITAL RATIO