Greenhouse Gas: Long-Run Growth and Collapse

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Key results from demand-driven model of growth and climate change

In business as usual (BAU) scenario, both atmospheric CO$_2$ concentration ($G$) and the capital/population ratio ($\kappa = K/N$) swing up for 70-80 years.

Then $\kappa$ crashes and stabilizes at a low level (along with output $X$, employment $L$, etc.). $G$ stabilizes as economy stagnates.

This dismal scenario can be countered by “mitigation” of emissions with an outlay of around 1.25% of GDP.
Variant One: BAU and Mitigated Scenarios

- Capital Stock per capita
- Greenhouse Gas Concentration
- Profit Share
- Employment
- Capital Utilization
- Investment Rate
- Output
- Labor Productivity
- Energy Productivity

\( \frac{\partial}{\partial t} (V^* - \Phi) \)
Quick summary:

Higher capital per capita increases output which in turn increases the speed of CO$_2$ accumulation.

Higher atmospheric CO$_2$ concentration reduces output and growth of capital per capita.

So we have a variation on “typical” predator-prey dynamics – $G$ is the predator and $\kappa$ the prey. After an upswing of $\kappa$ for around eight decades, there is a crash of output and capital only.
Key Features II

That is, \( \textit{CO}_2 \) concentration remains high, blocking any chance of economic recovery. Contrary to familiar wolf-and-moose models, the decay rate of \( \textit{CO}_2 \) in the atmosphere is very slow (the “wolf” is almost immortal).

In practice the system \textit{must} converge to a stationary state with constant capital stock, \( \textit{CO}_2 \) concentration, etc. Otherwise, \( \textit{CO}_2 \) accumulation will overwhelm the economy.
The model is set up to let output be determined by effective demand along Keynesian lines. Unemployment is possible, and shoots up after a climate-induced crash. Mainstream models assume full employment and Say’s Law.

Medium-term adjustment is also “predator-prey”

Output & jobs ↑ ⇒ profits ↓. Profits ↓ ⇒ output & jobs ↓ as investment ↓ (for simplicity this Marx/Goodwin business cycle is suppressed).
Key Features IV

Profits, investment, and output are also squeezed by rising CO$_2$ concentration $G$. Together with accounting equations for growth in $\kappa$ and $G$, this linkage determines dynamics of the model. Mainstream models get a similar result by assuming that higher $G$ forces supply of output down directly (with constant employment).
Energy Use and Productivity growth I

Simulations are set up to reach a stationary state at constant levels of population (initial level = 7 billion, final = 10), energy intensity $e = E/L$ (initial = 4 kilowatts per employed worker, final = 6) and labor productivity $\xi = X/L$ (initial = $20,000/\text{worker}$, final = $35,000$)

Productivity growth is key to increasing output. How is it determined?
Energy Use and Productivity growth II

See next slide for empirical linkages between growth rates of $e$ and $\xi$ – strong relationships (due to Gregor Semieniuk) in both cross-section and time series. That is, higher $e$ can be interpreted as pushing up $\xi$.

This linkage is an ostinato theme in ecological economics (Boulding, Daly) and plays a key role in determining the model’s results.
Stationary states with profit squeeze from both high employment and CO$_2$ concentration I

In the stationary state, capital formation is needed only to make up for depreciation at rate $\delta$, i.e.

$$g=\frac{I}{K}=\delta.$$

$G$ and $\kappa$ both push $g$ down so they must trade off along a “nullcline” to hold $g$ constant.

There is also a nullcline for $(\kappa, G)$ combinations that hold $G$ constant. Its slope is sensitive to mitigation $m$ as a share of GDP. A sufficiently high value of $m$ can steer the system away from a dismal BAU steady state.
Nullclines for per capita capital stock and CO$_2$ concentration (G) when the profit share decreases with both $\mu$ and $G$ and $G$.

Red Solid: BAU Nullclines  
Blue Dotted: $m\mu = 0.0125$ Nullclines
Stationary states with profit squeeze from both high employment and CO$_2$ concentration II

With no mitigation, $\kappa<20$ and $G=759$ in BAU stationary state (Initial values are $\kappa=28.57$ and $G=400$.)

Mitigated stationary state $G=486$ might correspond to 2.5$^\circ$C of global warming over the pre-industrial baseline – more than the currently accepted “red line”; BAU steady state with $G=759$ would mean 5 or 6$^\circ$C of warming.
Levels of Key Variables in Steady States

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<th>Profit share decreases with both $\kappa$ and $G$</th>
<th>Initial value</th>
<th>BAU</th>
<th>Mitigated</th>
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Higher $G$ increases depreciation rate

<table>
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<th></th>
<th>Initial value</th>
<th>BAU</th>
<th>Mitigated</th>
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Transient paths to steady state – BAU dynamics I

We set up simulations to track model dynamics toward a steady state. Growth trajectories are affected by assumed rates of increase of population, labor productivity, and energy intensity.
Transient paths to steady state – BAU dynamics II

Cyclical growth with crashes in capital per capita and output after around 8 decades.

CO$_2$ concentration *stabilizes* at well over 700 ppmv, so an atmospheric temperature increase of 5-6° Celsius. Output cannot recover.

Output stabilizes near its initial level of $60$ trillion so output per capita falls by around 35% at a final population level of 10 billion.
BAU simulation when the profit share decreases with both $\kappa$ and $G$

- Capital Stock per capita ($\kappa[t]$)
- Greenhouse Gas Concentration ($G[t]$)
- Capital Utilization ($u[t]$)
- Profit Share ($\pi[t]$)
- Employment ($\lambda[t]$)
- Investment Rate ($g[t]$)
- Output ($X[t]$)
- Labor Productivity ($\xi[t]$)
- Energy Productivity ($g[t]$)
Transient paths to steady state – Climate mitigation dynamics I

Now look at growth with mitigation at initial cost of $160 per metric ton of carbon, or $44 per ton of CO$_2$ (mid-range of current estimates).

With mitigation outlay of 1.25% of world output ($60 trillion initially) CO$_2$ concentration can be stabilized. This outlay is around one-half of current level of defense spending and roughly twice the level of worldwide energy consumption subsidies.
Transient paths to steady state – Climate mitigation dynamics II

$k$ and $X$ basically follow the growth path to a stationary state that would be observed in the absence of global warming.

BAU and 1.25% mitigation scenarios broadly correspond to the highest and lowest damage paths in the IPCC 2013

"Front-loading" mitigation leads to more favorable results ($G \approx 400$) – a “climate policy ramp” would be harmful.
BAU and mitigation simulations when the profit share decreases with both $\kappa$ and $G$.

Variant One: BAU and Mitigated Scenarios

- **Capital Stock per capita** ($\kappa[t]$)
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- **Output** ($X[t]$)
- **Labor Productivity** ($\xi[t]$)
- **Energy Productivity** ($g[t]$)
Transient paths to steady state – Climate mitigation dynamics III

These results are largely driven by convergence dynamics of $\kappa$ and $G$ to stationary levels.

Same basic pattern appears under variant medium-run adjustments, e.g. higher CO$_2$ concentration reduces profitability or leads to capital destruction via faster depreciation or shifts down a neoclassical aggregate production function in a supply-driven full employment Solow growth model.
Demand-driven and neoclassical dynamics

Dynamics of $\kappa$ for demand-driven and neoclassical growth specifications.
Transient paths to steady state – Impacts on labor

BAU stationary state employment/population ratio $\lambda$ is 65% below its initial value due to high $G$, stagnating $X$ and increases over time in $\xi$ and $N$. $\lambda$ rises in mitigated solution.

Wage share = Real wage/Productivity

The wage share stabilizes so that the real wage can rise over time roughly in line with labor productivity.

So BAU gives a high wage (per unit labor) and low employment long run. Mitigated solution is high wage, high employment.
Acknowledgements

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