Economic Growth and the Convergence in Carbon Emissions Across Countries

M. Scott Taylor
Department of Economics, Calgary
Institute for Advanced Policy Research, Calgary
National Bureau of Economic Research, Cambridge MA
The Environment and Growth

• Is continuing economic growth compatible with an improving environment?

• What determines cross country differences in environmental quality?
Problem

• Continual growth with environmental improvement requires falling emissions per unit of output.

• *But* lowering emissions per unit of output comes at increasing cost, *because of* Diminishing Returns.
Implication

• Pollution abatement costs should rise precipitously

• This lowers the return to investment

• This should choke off growth
Potential Solution

• Technological progress holds costs down

• The return to capital accumulation is not choked off

• Growth with environmental improvement is possible
Is it possible?

• Maybe
The Solow Model

• One Aggregate Good produced via capital equipment and labor
• Aggregate output can be consumed or invested
• Capital accumulates over time via investment
• Technological progress makes inputs to goods production more efficient over time.
\[ Y = C + I \]
\[ Y = F(K, BL) \]
\[ I = sY \]

\[ \frac{dK}{dt} = sF(K, BL) - \delta K \]

\[ \frac{dB}{dt} = Bg \quad g > 0 \quad \frac{dL}{dt} = Ln \quad n > 0 \]

\[ K(0) = K_0 \quad B(0) = B_0 \quad L(0) = L_0 \]
Rewrite in Different Units

Define: \( k = K / BL \), \( y = Y / BL \), etc.

Manipulate to find:

\[
\frac{dk}{dt} = sf(k) - [\delta + g + n]k
\]

\( k(0) \) given and \( f(k) = F(K / BL, 1) \)
The Solow Model

Output
Savings
Investment

\( (n+g+\delta)k \)

\( f(k) \)

\( sf(k) \)

Capital per effective worker
BGP Predictions

• Technological progress determines an economy’s long run growth.
• $k^*$ is constant along the BGP, but this means:
• Capital per worker, $K/L$ grows at rate $g$
• Income per capita $Y/L$ grows at rate $g$
• Aggregate output grows at rate $g+n$
Transition Path Predictions

\[
\frac{dk}{dt} = \frac{sf(k)}{k} - [\delta + g + n]
\]

Rates of Change

\[
\frac{dk}{dt} = \frac{sf(k)}{k} - [\delta + g + n]
\]

Capital per effective worker

k(0) -> k^*
Unconditional Convergence
Poor Countries Should grow faster than Rich ones

Figure 1.1
Simple correlation between growth and level of GDP
Rates of Change

\( \frac{dk}{dt} \)

\( \frac{k}{k} \)

Transition Path Predictions

\( (n' + g + \delta) \)

\( (n + g + \delta) \)

\( sf(k)/k \)

\( s'f(k)/k \)

Capital per effective worker

\( k' \)

\( k^* \)
Conditional Convergence
Correct for SS differences

Figure 1.2
Growth rate versus level of GDP
The Green Solow Model

- Technological progress makes inputs used in both goods production and abatement more efficient over time.

- Environmental standards rise slowly over time
Emissions produced are proportionate to output flow

\[ E = \Omega[F - A(F, \theta)] \]

Emissions can be abated but at some cost

\[ \frac{d\Omega}{dt} = -\Omega g_A \quad \text{where} \quad g_A > 0 \]

\[ \Omega(0) = \Omega_0 \]
Manipulate to Obtain

\[ \frac{dE}{dt} = \alpha \frac{k}{k} + \left[ g + n - g_A \right] \]

Transitional Growth Component

Emissions Growth along BGP Defined as \( G_E = g + n - g_A \)
Two Time Frames

• Along the BGP we again have $\frac{dk}{dt} = 0$

• Emissions fall or rise over time

• If $G_E > 0$ we say growth is unsustainable

• If $G_E < 0$ we say growth is sustainable
Rates of Change

$\frac{dk}{dt}/k$

$\frac{dE}{dt}/E$

Sustainable Growth: $G_E < 0$

$\alpha(n+g+\delta)-G_E$

$\alpha(n+g+\delta)$

$\alpha sf(k)/k$

Capital per effective worker

$k^T$

$k^*$
Empirical Implications
Declining Emissions to GDP ratios

![Graph showing declining emissions to GDP ratios from 1950 to 1995 for various pollutants such as SO, NOx, VOCs, PM10, and CO. The x-axis represents years from 1950 to 1995, and the y-axis represents the ratio of tons of emissions to dollars (1940=100). The graph indicates a consistent decline in emissions to GDP ratios over time.]
Pollution Abatement costs/GDP are virtually constant.
Carbon Monoxide Emissions, 1940-1998
Nitrogen Oxide Emissions, 1940-1998
Volatile Organic Compounds 1940-1998

The chart illustrates the emissions of volatile organic compounds from various sources over the period from 1940 to 1998. The emissions are categorized into five main sources:

- **Fuel Combustion**
- **Industrial Processing**
- **Solvent Utilization**
- **On-road**
- **Non-road**

The data shows a significant increase in emissions in the mid-1960s, peaking in the late 1960s and early 1970s, followed by a gradual decline through the 1980s and 1990s. The emissions from different sources vary, with some showing a more pronounced increase and others showing a more gradual trend.
Particulate Matter PM10, 1940-1998

Graph showing the emissions of particulate matter PM10 from 1940 to 1998, categorized by source type.
What if Growth is Unsustainable?
UnSustainable Growth: $G_E > 0$

Rates of Change

$\frac{dE}{dt}/E$

$\alpha(n+g+\delta)$

$\alpha(n+g+\delta)-G_E$

$\alpha f(k)/k$

$k^*$

$k^T$

Capital per effective worker
Unconditional Convergence
Conditional Convergence

Average Log Changes 1998-1960 vs. Log Lbs/capita 1960
Estimated Rate of Convergence

Rate of convergence is 2% per year.
This implies:

• 35 years to halve the gap between current position and steady state

• Observation of positive emission growth for a very long period is consistent with “sustainable” growth.

• Could Carbon be like sulfur, nitrogen oxides, particulates, etc?
Conclusions

• Green Solow model offers a consistent explanation for observed data on emission levels, emission intensities, and environmental control costs.

• Predicts conditional convergence in emissions per person. Estimated rate of convergence is very slow. 2% per year.
• Predicts eventually rising environmental quality if technological progress is sufficiently rapid

• Left to do: Other pollutants and European countries; rest of the world and Carbon emissions; other estimation strategies.