Trade, Growth and the Environment

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• Good morning and thank you for inviting me to visit beautiful Quebec City and speak to you today.

• In the next 50 minutes, I am going to pose and then answer 3 questions central to our understanding of sustainability. To answer my 3 questions I am going to develop a simple growth model I call the Green Solow model and then use it to make sense of cross-country data on pollution emissions, pollution abatement costs, and emission intensities. I will use it to pinpoint what I think is the critical ingredient for sustainability, and in the final slide, I will also use the model, and what we have learnt from other pollutants, to speculate about the likelihood of success in controlling carbon emissions. Fifty minutes isn't a lot of time so I am going to leave out many details, and I will proceed quite quickly. For those of you who would like more background information, please see the references on the last slide of my presentation, and feel free to email me in Calgary with any follow-up questions.
What are the Issues?

• Is continuing economic growth compatible with an improving environment?

• What determines cross country differences in environmental quality?

• Does international trade shift dirty pollution industries to less developed countries?
The Growth Dilemma

• 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 as emissions per unit of output fall.
- Higher costs must lower the return to investment
- This slows or even chokes off growth.
A Potential Solution

• Technological progress holds abatement costs down

• The return to capital accumulation is not choked off

• Growth with environmental improvement is possible
Is it possible?

• Maybe – but what would it require?

• Is there any evidence that it has occurred for any pollutant in any country?

• What does this evidence tell us about our future with carbon regulation?
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

- The Solow Model
- Output
- Savings
- Investment

\[ y^* \]
\[ i^* \]
\[ f(k) \]
\[ sf(k) \]

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

- Capital per effective worker
BGP Predictions

- $k^*$ 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 $g+n$

- Technological progress determines an economy’s long run growth.
Transition Path Predictions

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

Rates of Change

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

Capital per effective worker

k(0)

k*

(n+g+δ)

sf(k)/k
Unconditional Convergence
Poor Countries Should grow faster than Rich ones

Figure 1.1
Simple correlation between growth and level of GDP
Transition Path Predictions

Rates of Change

\[ \frac{dk}{dt} \]

\[ \frac{k}{k} \]

Capital per effective worker

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

\[ (n+g+\delta) \]

\[ sf(k)/k \]

\[ s'f(k)/k \]
Conditional Convergence
Correct for SS differences
Summary

• Technological Progress is key to growth

• Two time periods: transition and balanced growth.

• Convergence in incomes per capita, after conditioning on country characteristics.
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.

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

Emissions can be abated but at some cost.

\[ \theta F \text{ is Abatement costs} \]
\[ \theta \text{ is Abatement costs/GDP} \]

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

\[ \Omega(0) = \Omega_0 \]
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 have $dk/dt = 0$

• Emissions fall or rise over time

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

• If $G_E < 0$ we say growth is sustainable
Sustainable Growth: $G_E < 0$

Rates of Change

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

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

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

$\alpha sf(k)/k$

Capital per effective worker

$k^T$  
$k^*$
The Green Solow Model
Environmental Kuznets Curve

Environmental Quality (Weak case) = Environmental Quality (Strong Case)
Emissions (Weak case) = Emissions (Strong case)
Empirical Implications
When Growth is Sustainable

• The Environmental Kuznets Curve: Pollution emissions should at first rise with development and then fall

• Pollution Abatement costs should rise, but as a fraction of output are constant.

• Emissions per unit of output fall continuously.
US Evidence
Declining Emissions to GDP ratios
Pollution Abatement costs/GDP are virtually constant.
Sulfur Dioxide Emissions, 1940-1998
Nitrogen Oxide Emissions, 1940-1998

- Fuel Combustion
- Industrial Processing
- On-road
- Non-road
- Miscellaneous
Particulate Matter PM10, 1940-1998

The graph depicts the emissions of particulate matter PM10 from 1940 to 1998, categorized by source types: Fuel Combustion, Industrial Processing, On-road, Non-road, and Miscellaneous. The emissions are measured in million short tons. The data shows a significant decrease in emissions over the years, particularly in the later years, indicating improved environmental regulations and practices.
Carbon Monoxide Emissions, 1940-1998
## International Evidence

<table>
<thead>
<tr>
<th>Countries</th>
<th>NOx</th>
<th>Peak</th>
<th>SOx</th>
<th>Peak</th>
<th>CO</th>
<th>Peak</th>
<th>VOC</th>
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</table>
For key local pollutants

- Growth and environmental improvement can co-exist.

- Regulations tightened but costs did not skyrocket.

- Some evidence it was technological progress in abatement.
Should we be Optimistic?

• What about Trade?

• What about Unsustainable paths like the one for Carbon?
What about Trade?

• Maybe the reduction in US pollution levels is matched by increases elsewhere as dirty industries migrate to less developed countries?

• What looks like success is really failure to address the problem.
Perhaps, but

- Pollution abatement costs are a small fraction of output for all OECD countries suggesting that other determinants of location could be important.
# Pollution Abatement Costs as a Share of GDP

<table>
<thead>
<tr>
<th>Country</th>
<th>Cost of GDP as a Share of GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>0.8</td>
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<tr>
<td>Austria</td>
<td>2.2</td>
</tr>
<tr>
<td>Belgium</td>
<td>1.4</td>
</tr>
<tr>
<td>Canada</td>
<td>1.2</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>2.0</td>
</tr>
<tr>
<td>Finland</td>
<td>1.1</td>
</tr>
<tr>
<td>France</td>
<td>1.4</td>
</tr>
<tr>
<td>Germany</td>
<td>1.6</td>
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<tr>
<td>Hungary</td>
<td>0.6</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.6</td>
</tr>
<tr>
<td>Italy</td>
<td>0.8</td>
</tr>
<tr>
<td>Japan</td>
<td>1.3</td>
</tr>
<tr>
<td>Korea</td>
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<td>Netherlands</td>
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<tr>
<td>Norway</td>
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<td>Poland</td>
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<td>Slovak Republic</td>
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<tr>
<td>Sweden</td>
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<td>Switzerland</td>
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<td>Turkey</td>
<td>1.1</td>
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<tr>
<td>United Kingdom</td>
<td>0.7</td>
</tr>
<tr>
<td>United States</td>
<td>1.5</td>
</tr>
</tbody>
</table>
• Except for very natural resource intensive industries, the developed world dominates dirty good exports.
<table>
<thead>
<tr>
<th>Exporting Country</th>
<th>Value ($mill.)</th>
<th>World trade share (%)</th>
<th>Share in country exports (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Germany</td>
<td>45.6</td>
<td>11.9</td>
<td>15.8</td>
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<tr>
<td>2 United States</td>
<td>28.5</td>
<td>7.4</td>
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<td>3 Canada</td>
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<td>4 France</td>
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<td>5 Belgium-Luxembourg</td>
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<td>7 Japan</td>
<td>18.9</td>
<td>4.9</td>
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<td>8 United Kingdom</td>
<td>17.3</td>
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<td>9 Italy</td>
<td>16</td>
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<tr>
<td>10 Sweden</td>
<td>15.3</td>
<td>4</td>
<td>33</td>
</tr>
</tbody>
</table>
What about Unsustainable Growth

• Pollution emissions should rise rapidly with development and grow more slowly thereafter.

• Emissions per unit of output may fall, but just not fast enough.

• Carbon is a prime example.
UnSustainable Growth: $G_E > 0$

Rates of Change

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

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

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

$\alpha\frac{sf(k)}{k}$

$k^*$

$k^T$

Capital per effective worker
Transition Path Predictions

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

\[
\frac{dE}{dt} - n = \alpha \frac{\dot{k}}{k} + [g - g_A]
\]
Unconditional Convergence
Conditional Convergence

![Graph showing Conditional Convergence](image-url)
Summing Up
Local Pollutants

• US and International evidence suggests that growth and environmental improvement is possible, but not inevitable.

• Environmental improvement came at relatively low costs (1 to 2% of GDP)

• Green Solow model attributes this success to technological progress in abatement holding down the costs of slowly rising environmental standards.
Trade’s Role

• Fears of lost competitiveness from pollution regulation are over blown.

• Industry location depends on many more factors than just environmental regulation.

• Rich developed countries are the big dirty good producers and exporters.
What is our Carbon future?

• Convergence in emissions per capita across countries is likely even absent active regulation.

• BUT with real economic growth of 3% per year, Canada’s historic emission intensity reductions of 1.5 – 2%/year have to at least double in the long run.

• Rates of reduction far in excess of 3%/yr have been achieved by other countries, for other pollutants, and for only small costs.

• Sustainability is not only possible, it is probably quite cheap.
Additional Reading


