Confessions of a Team that did
\textit{Interdisciplinary Research}

Warren Sanderson, Erich Striessnig
Wolfgang Schöpp, Markus Amann
Why Confessions?

• Interdisciplinary research is something that many people say they want to do, but few actually admit doing it.
Interdisciplinary Research
"I'm on the verge of a major breakthrough, but I'm also at that point where chemistry leaves off and physics begins, so I'll have to drop the whole thing."
The Grand Programs Involved

- Mitigation of Air Pollution (MAG)
- World Population (POP)
Our offspring

Effects on Well-Being of Investing in Cleaner Air in India
Take Home Messages

• Interdisciplinary Research can be done.

• It can be fun.

• It can be productive.
What’s in a name?

• Effects on Well-Being of Investing in Cleaner Air in India

• Well-Being

• Cleaner Air
The Model Parents

- **GAINS MODEL**
- Greenhouse Gas and Air Pollution Interactions and Synergies Model

- **SEDIM**
- Simple Economic and Demographic Interaction Model
Disciplines

• Energy Systems
• Atmospheric Chemistry
• Epidemiology
• Economics
• Demography
The Offspring’s Accomplishments

• “In India, air pollution abatement investments clearly improve well-being.”
Organization

• 1. This Introduction
• 2. The GAINS Model – Markus Amann
• 3. The SEDIM Model – Warren Sanderson
• 4. Putting it all together in a coherent and publishable package – Erich Striessnig
• 5. YSSP research – Haochen Wang
• 6. Panel Discussion of Future Interdisciplinary Research
Economic Growth in a World of Environmental Constraints

The SEDIM Model
Constraints

• The 20\textsuperscript{th} century was the century of growth.
• The 21\textsuperscript{st} century is going to be the century of constraints.

• How can we think about integrating these constraints into an economic model?
Environmental Constraints

• Challenges posed by global climate change
• Economic costs of necessary abatement policies modeling the impact of environmental degradation on human health and productivity
• Challenges posed by energy and natural resource scarcity
• Substitution technologies transition to renewable energies
Demographic Constraints

• Challenges posed by unprecedented societal aging in some parts of the world
• include realistic demography
• think about how aging societies are different from “stable populations”
• Opportunities generated by favorable age-structure dynamics in others
• How to make the most out of a potential “demographic dividend”?
• How to model the ongoing educational transitions?
Challenges for the Economic Growth Modeler

• Any realistic model of economic growth has to take environmental challenges into account.
  – The constraints will be different in different parts of the world
  – There is enormous uncertainty
Are We Really in Equilibrium

- Many economic growth models assume that we are:
  - 1. in equilibrium
  - 2. have perfect foresight (or rational expectations)
  - 3. and therefore there are no surprises.
- (we know all our environmental problems with certainty today)
Do We Believe This?

• In a world of unanticipated environmental change and unanticipated costs, the assumption of perfect foresight makes no sense.
Out of Equilibrium

• We need a model capable of studying out-of-equilibrium dynamics.
Enter SEDIM

- SEDIM does not assume perfect foresight
- agents are characterized by adaptive, forward-looking behavior
- they make use of limited common information on how the economy evolved in the past...
- ...using this information they “plan ahead” and react to surprises.
One type of output, $Y_t$, is generated, using a Cobb-Douglas production function

$$Y_t = A_t \times L^\alpha \times K^{1-\alpha}$$

Anything that causes economic growth, has to do so by affecting one of these sources:

$L_t$... Effective Labor
$K_t$... Capital Stock
$A_t$... Total Factor Productivity
($\alpha$... Output Elasticity of Labor)
The workforce in SEDIM includes the full information on the population’s age- and educational attainment structure

\[ L_t = \sum_{a=\text{alfe}(t)}^{\text{alfx}(t)} \text{POP}_{a,t} \text{EU}_{a,t} \]

\text{alfe}(t) \ldots \text{age of labor market entry in year } t
\text{alfx}(t) \ldots \text{age of labor market exit in year } t
\text{POP}_{a,t} \ldots \text{population at age } a \text{ in year } t

\text{EU}_{a,t} \ldots \text{number of efficiency units embodied by worker of age } a \text{ in year } t
Capital

• There are two types of capital holders
  – Consumers
  – Corporations and wealthy individuals
Capital

• Consumers have income from labor and from capital assets. They save for life-cycle purposes.

• Their goal is to smooth consumption over their lifetime.

• BUT consumers have imperfect foresight.
Corporations

- Corporations and wealthy individuals receive income from capital investments.
- Their income depends on the rate of return to capital.
- They do not save for life-cycle consumption smoothing.
Total Factor Productivity

SEDIM is a model of conditional convergence/divergence characterized by two gaps

a country’s “technological gap” with respect to the global technological leader
a country’s gap to its own “potential” level of $A_t$

Determining factors of a country’s “potential”, its “backwardness”, and the speed of catching-up include:
- rate of capital formation
- educational attainment level of the workforce
- population age-structure
- the interaction of education and age-structure
- an economy’s level of “openness”
- the quality of political institutions, i.e., corruption, rule of law
Measuring Well-Being

• In our paper in ES&T, we measured well-being using a version of the UN’s Human Development Index.

• Erich Striessnig will say more about this in a moment.
Challenge

• Reproducing India’s pattern of economic growth as it happened in the past and as it is expected to happen in the future.

• We did this by altering the rate of total factor productivity in a way that was consistent with the policy changes actually observed in India.
Interdisciplinarity

• SEDIM initially contained ideas from two disciplines:
  – Economics
  – Demography

• To do the research on India, we added a third discipline:
  – Epidemiology
The GAINS (Greenhouse Gases - Air Pollutants Interactions and Strategies) model - Applications in Europe and Asia

Markus Amann
Program Director
Mitigation of Air Pollution and Greenhouse Gases
How has pollution been reduced in Europe?

SO₂ emissions in Western Europe: A 1970’s perspective

SO₂ avoided through:
- energy efficiency improvements
- changes in fuel structure
- (end-of-pipe) emission controls

Actual SO₂

Hypothetical GDP
(3% growth/yr)

Actual GDP
(constant 2000 Euro)
How has pollution been reduced in Europe?

SO$_2$ emissions in Western Europe: 1945-2010

SO$_2$ avoided through

- Actual SO$_2$
- Hypothetical GDP (3% growth/yr)

Source: IIASA
http://gains.iiasa.ac.at
How has pollution been reduced in Europe?

Decoupling between GDP and SO$_2$ emissions in Western Europe

SO$_2$ avoided through
- energy efficiency improvements
- changes in fuel structure
- (end-of-pipe) emission controls
- Actual SO$_2$
- Hypothetical GDP (3% growth/yr)

Source: IIASA
http://gains.iiasa.ac.at
# GAINS:
## A multi-pollutant/multi-effect systems perspective

<table>
<thead>
<tr>
<th></th>
<th>PM (BC, OC)</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>VOC</th>
<th>NH₃</th>
<th>CO</th>
<th>CO₂</th>
<th>CH₄</th>
<th>N₂O</th>
<th>HFCs</th>
<th>PFCs</th>
<th>SF₆</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Health impacts:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM (Loss in life expectancy)</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₃ (Premature mortality)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vegetation damage:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₃ (AOT40/fluxes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidification (Excess of critical loads)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eutrophication (Excess of critical loads)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Climate impacts:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-term (GWP100)</td>
<td>(√)</td>
<td>(√)</td>
<td>(√)</td>
<td>(√)</td>
<td>(√)</td>
<td>(√)</td>
<td>(√)</td>
<td>(√)</td>
<td>(√)</td>
<td>(√)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near-term forcing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon deposition to the Arctic and glaciers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(√)</td>
</tr>
</tbody>
</table>

- √: Present
- (√): Not applicable
Origin of PM2.5 - 2009

Netherlands average of the urban AIRBASE stations

Lyon, Centre Ville

Source: IIASA GAINS
Origin of PM2.5 - 2009

**Netherlands**

average of the urban AIRBASE stations

- **Origin of PM2.5 - 2009**

- **Source:** IIASA GAINS

---

**Lyon, Centre Ville**

**Source:** IIASA GAINS

- **Origin**
IIASA’s GAINS systems approach for cost-effective emission reduction strategies

There are large international differences in
• emission densities,
• potentials and costs of further measures,
• sensitivities of ecosystems,
• meteorological and climatic conditions, etc.
Policy applications of GAINS

GAINS has been the key scientific tool for

• international environmental agreements, e.g.
  • UN-ECE LRTAP
  • EU air quality and climate policies

• international assessments
  • UNEP
  • IPCC
  • AMAP
The target of the Thematic Strategy on Air Pollution for 2030

Current legislation 2030: 5 months life shortening

Commission proposal: 67% ‘gap closure’ in 2030: -50% health impacts compared to 2005

Maximum additional controls: 3.6 months life shortening

Loss in statistical life expectancy

Total health benefits vs. total emission control costs

Marginal health benefits vs. marg. emission control costs

Optimal range for gap closure

Marginal health benefits vs. marg. emission control costs
Range of future global emissions
HTAP/GAINS policy scenarios vs RCP

Source: GAINS model; ECLIPSE V5 scenario
Co-benefits from an air quality perspective

Costs for reducing PM2.5 population exposure in China by 50%

Cost-effective portfolios to improve air quality include measures that also reduce long-lived GHGs

Source: GAINS-Asia
Conclusions

• GAINS provides an integrated management approach for air pollution and greenhouse gases: multi-pollutant/multi-effect, multiple scale, cost-effectiveness

• GAINS shapes air quality and climate policies in Europe and Asia, provides focus on co-benefits

• GAINS has a long history of policy applications in Europe
Well-being and the Macro-economic Effects of Investing in Cleaner Air in India

Warren Sanderson\textsuperscript{1,2}, Erich Striessnig\textsuperscript{1,3}, Wolfgang Schöpp\textsuperscript{1}, Markus Amann\textsuperscript{1}

\textsuperscript{1}International Institute for Applied Systems Analysis (IIASA)

\textsuperscript{2}Stony Brook University (SUNY)

\textsuperscript{3}Vienna University of Economics and Business (WU)

Population Association of America 2013 Annual Meeting
New Orleans, April 12
Outline

1. Introduction
2. The SEDIM Model
3. Case Study of India
4. Conclusion
The Future of Economic Growth Modeling

1. Environmental Constraints
2. Demographic Constraints
Environmental Constraints

- Challenges posed by global climate change
  - economic costs of necessary abatement policies
  - modeling the impact of environmental degradation on human health and productivity
- Challenges posed by energy and natural resource scarcity
  - substitution technologies
  - transition to renewable energies
Demographic Constraints

- Challenges posed by unprecedented societal aging
  - Think about how aging societies are different from “stable populations”
- Opportunities generated by favorable age-structure dynamics
  - How to make the most out of a potential “demographic dividend”?
- Include **realistic demography**!
- How to model the ongoing educational transitions?
The SEDIM Model

SEDIM
Simple Economic Demographic Interaction Model
The SEDIM Model

SEDIM
Simple Economic Demographic Interaction Model

- Agents’ are characterized by adaptive, forward looking behavior.
- They make use of limited common information on how the economy evolved in the past…
- …using this information, they “plan ahead”
- They are able to react to “surprises”!
- SEDIM does not assume perfect foresight
Case Study

Well-being and the Macro-economic Effects of Investing in Cleaner Air in India
Main Research Question:

What effect do environmental regulations have on well-being?

- Economic growth in India accompanied by tremendous increases in emission concentration levels.
- Policies aimed at implementing stringent emission standards likely to result in huge health benefits.
- We need a model which can balance the health benefits on the one hand and the economic costs on the other.
What is $PM_{2.5}$?

**Definition**

$PM_{2.5}$ is particulate matter with a diameter of 2.5 microns or less.
What is $PM_{2.5}$?

**Definition**

$PM_{2.5}$ is particulate matter with a diameter of 2.5 microns or less

- This stuff kills people!
What is $PM_{2.5}$?

**Definition**

$PM_{2.5}$ is particulate matter with a diameter of 2.5 microns or less

- **This stuff kills people!**
- **Well documented**
  - Pope et. al. (New England Journal of Medicine, 2009)
    
    “*a* decrease of 10 $\mu g$ per cubic meter in the concentration of fine particulate matter was associated with an estimated increase in mean ($\pm SE$) life expectancy of 0.61 ± 0.20 year ($P = 0.004$).”
  
  - Brook et. al. (Journal of the American Heart Association, 2010)
    “overall evidence is consistent with a causal relationship between $PM_{2.5}$ exposure and cardiovascular morbidity and mortality.”
Why India?

<table>
<thead>
<tr>
<th></th>
<th>Delhi</th>
<th>Mumbai</th>
<th>Kolkata</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PM_{2.5}$</td>
<td>99</td>
<td>52</td>
<td>73</td>
</tr>
</tbody>
</table>

**Table 1:** Ambient concentrations of $PM_{2.5}$ for various cities in 2005 in $\mu g/m^3$. Source: GAINS
Why India?

Table 1: Ambient concentrations of $PM_{2.5}$ for various cities in 2005 in $\mu g/m^3$. Source: GAINS

<table>
<thead>
<tr>
<th></th>
<th>Delhi</th>
<th>Mumbai</th>
<th>Kolkata</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PM_{2.5}$</td>
<td>99</td>
<td>52</td>
<td>73</td>
</tr>
</tbody>
</table>

The WHO-standard for $PM_{2.5}$ is $10\mu g/m^3$!
Indian Current Legislation (ICL)

- Controls on dust emissions from the power sector and industry accounting for national emissions limit values
- Low sulfur liquid fuels for the residential, commercial and transport sectors
- Slow penetration of improved cooking stoves using biomass
- CNG for buses and three wheelers in urban areas
- Emission limit values for road transport sources up to Euro 4/IV
- Emissions of sulfur from the power sector and industry remain uncontrolled

European Current Legislation (ECL)

- EU-legislation
  - stationary sources in the power sector and industry (Proposal for the Industrial Emissions Directive)
  - transport sources: phasing-in EU legislation up to EURO 6/IV for road transport and up to stage IV for non-road sources
- National legislation on industrial and small combustion sources (if stricter than the EU-wide legislation)

These two policy interventions will be compared to a **no additional-control** (NOC) scenario.
Reform Schedule

1. Phasing-in (2010-2019)
   - gradual implementation of the emission regulations set by the reform
   - modeled as the building up of the total necessary abatement capital stock

2. Maintenance Phase (2020-2030)
   - abatement capital in place has to be maintained and operated
   - additional costs from new facilities that also have to comply with the new standard

Note: We do not maintain a certain level of $PM_{2.5}$ concentration, but a certain standard of emissions
## Costs and Benefits

<table>
<thead>
<tr>
<th>Year</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0.00%</td>
<td>0.15%</td>
<td>0.54%</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>2015</td>
<td>0.00%</td>
<td>0.15%</td>
<td>0.55%</td>
<td>60</td>
<td>52</td>
<td>38</td>
</tr>
<tr>
<td>2020</td>
<td>0.00%</td>
<td>0.15%</td>
<td>0.43%</td>
<td>74</td>
<td>57</td>
<td>30</td>
</tr>
<tr>
<td>2030</td>
<td>0.00%</td>
<td>0.12%</td>
<td>0.29%</td>
<td>116</td>
<td>72</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 2: Cost as a fraction of GDP and $PM_{2.5}$ concentrations (in $\mu g/m^3$) in three scenarios, India, 2010, 2015, 2020, 2030. Source: GAINS
Costs and Benefits

<table>
<thead>
<tr>
<th>Year</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0.00%</td>
<td>0.15%</td>
<td>0.54%</td>
</tr>
<tr>
<td>2015</td>
<td>0.00%</td>
<td>0.15%</td>
<td>0.55%</td>
</tr>
<tr>
<td>2020</td>
<td>0.00%</td>
<td>0.15%</td>
<td>0.43%</td>
</tr>
<tr>
<td>2030</td>
<td>0.00%</td>
<td>0.12%</td>
<td>0.29%</td>
</tr>
</tbody>
</table>

Cost as fraction of GDP

<table>
<thead>
<tr>
<th>Year</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>2015</td>
<td>60</td>
<td>52</td>
<td>38</td>
</tr>
<tr>
<td>2020</td>
<td>74</td>
<td>57</td>
<td>30</td>
</tr>
<tr>
<td>2030</td>
<td>116</td>
<td>72</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 2: Cost as a fraction of GDP and PM$_{2.5}$ concentrations (in $\mu g/m^3$) in three scenarios, India, 2010, 2015, 2020, 2030. Source: GAINS

- In 2005 India spent around 3.8% of GDP on health and 3.23% on education (Source: WDI)
Effects of $PM_{2.5}$ in SEDIM

1. Effect of mortality
2. Effect of morbidity
Effects of $PM_{2.5}$ in SEDIM

1. Effect of mortality
   - Each additional $10 \mu g/m^3$ of $PM_{2.5}$ increases the relative risk of dying at adult ages (>30) by 4%.
     - changes the age- and education structure of the population
     - people adapt their savings behavior
     - changes in the rate of capital formation as well as changes in the population age- and education structure affect the rate of technological change

2. Effect of morbidity
Effects of $PM_{2.5}$ in SEDIM

1. Effect of mortality
2. Effect of morbidity

- Each additional 10 μg/m$^3$ of $PM_{2.5}$ increases the number of work-loss days by 0.046 (Source: Hurley et. al. 2005)
  - affects the effective labor force
## Results: GDP

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>4.96</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2015</td>
<td>7.16</td>
<td>1.000</td>
<td>1.001</td>
</tr>
<tr>
<td>2020</td>
<td>9.90</td>
<td>1.000</td>
<td>1.003</td>
</tr>
<tr>
<td>2030</td>
<td>16.79</td>
<td>1.001</td>
<td>1.007</td>
</tr>
</tbody>
</table>

Table 3: Total GDP, GDP per capita, and GDP per worker in three scenarios, India, 2010, 2015, 2020, 2030. Notes: NOC in 2000 international US$. Numbers in ICL and ECL relative to NOC.
## Results: GDP

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>4.96</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2015</td>
<td>7.16</td>
<td>1.000</td>
<td>1.001</td>
</tr>
<tr>
<td>2020</td>
<td>9.90</td>
<td>1.000</td>
<td>1.003</td>
</tr>
<tr>
<td>2030</td>
<td>16.79</td>
<td>1.001</td>
<td>1.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>4073</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2015</td>
<td>5514</td>
<td>1.000</td>
<td>1.001</td>
</tr>
<tr>
<td>2020</td>
<td>7200</td>
<td>0.999</td>
<td>1.000</td>
</tr>
<tr>
<td>2030</td>
<td>11135</td>
<td>0.996</td>
<td>0.995</td>
</tr>
</tbody>
</table>

**Table 3:** Total GDP, GDP per capita, and GDP per worker in three scenarios, India, 2010, 2015, 2020, 2030. Notes: NOC in 2000 international US$. Numbers in ICL and ECL relative to NOC.
Table 3: Total GDP, GDP per capita, and GDP per worker in three scenarios, India, 2010, 2015, 2020, 2030. Notes: NOC in 2000 international US$. Numbers in ICL and ECL relative to NOC.
### Results: Consumption

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>3065</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2015</td>
<td>4291</td>
<td>0.998</td>
<td>0.993</td>
</tr>
<tr>
<td>2020</td>
<td>5702</td>
<td>0.997</td>
<td>0.993</td>
</tr>
<tr>
<td>2030</td>
<td>9213</td>
<td>0.995</td>
<td>0.992</td>
</tr>
</tbody>
</table>

**Table 4:** Forecasted consumption per capita and $PM_{2.5}$ concentration in three scenarios, India, 2010, 2015, 2020, 2030. Notes: Consumption per capita in NOC in 2000 international US$. Consumption in ICL and ECL relative to NOC.
Results: Consumption

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>3065</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2015</td>
<td>4291</td>
<td>0.998</td>
<td>0.993</td>
</tr>
<tr>
<td>2020</td>
<td>5702</td>
<td>0.997</td>
<td>0.993</td>
</tr>
<tr>
<td>2030</td>
<td>9213</td>
<td>0.995</td>
<td>0.992</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>2015</td>
<td>60</td>
<td>52</td>
<td>38</td>
</tr>
<tr>
<td>2020</td>
<td>74</td>
<td>57</td>
<td>30</td>
</tr>
<tr>
<td>2030</td>
<td>116</td>
<td>72</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 4: Forecasted consumption per capita and $PM_{2.5}$ concentration in three scenarios, India, 2010, 2015, 2020, 2030. Notes: Consumption per capita in NOC in 2000 international US$. Consumption in ICL and ECL relative to NOC.
## Results: Longevity

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>70.5</td>
<td>70.5</td>
<td>70.5</td>
</tr>
<tr>
<td>2015</td>
<td>71.8</td>
<td>72.0</td>
<td>72.5</td>
</tr>
<tr>
<td>2020</td>
<td>72.9</td>
<td>73.5</td>
<td>74.4</td>
</tr>
<tr>
<td>2030</td>
<td>74.9</td>
<td>76.2</td>
<td>77.7</td>
</tr>
</tbody>
</table>

**Table 5**: Life expectancy at birth and lives saved for three different scenarios, India, 2010, 2015, 2020, 2030. Notes: “Lives saved” refers to the difference in the number of people dying in that year in the respective scenario and NOC.
## Results: Longevity

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>70.5</td>
<td>70.5</td>
<td>70.5</td>
</tr>
<tr>
<td>2015</td>
<td>71.8</td>
<td>72.0</td>
<td>72.5</td>
</tr>
<tr>
<td>2020</td>
<td>72.9</td>
<td>73.5</td>
<td>74.4</td>
</tr>
<tr>
<td>2030</td>
<td>74.9</td>
<td>76.2</td>
<td>77.7</td>
</tr>
</tbody>
</table>

### Life Expectancy at Birth

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2015</td>
<td>0</td>
<td>179</td>
<td>462</td>
</tr>
<tr>
<td>2020</td>
<td>0</td>
<td>423</td>
<td>1106</td>
</tr>
<tr>
<td>2030</td>
<td>0</td>
<td>1212</td>
<td>2527</td>
</tr>
</tbody>
</table>

### Annual Averted Deaths in 1000s

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NOC</th>
<th>ICL</th>
<th>ECL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2015</td>
<td>0</td>
<td>179</td>
<td>462</td>
</tr>
<tr>
<td>2020</td>
<td>0</td>
<td>423</td>
<td>1106</td>
</tr>
<tr>
<td>2030</td>
<td>0</td>
<td>1212</td>
<td>2527</td>
</tr>
</tbody>
</table>

**Table 5:** Life expectancy at birth and lives saved for three different scenarios, India, 2010, 2015, 2020, 2030. Notes: “Lives saved” refers to the difference in the number of people dying in that year in the respective scenario and NOC.
Political implications
Political implications

- In India investments in reducing $PM_{2.5}$ will have no discernible effect on GDP growth
Political implications

- In India investments in reducing $PM_{2.5}$ will have no discernible effect on GDP growth
- The large increase in longevity outweighs the small decreases in the mean level of educational attainment and GDP per capita
Political implications

- In India investments in reducing $PM_{2.5}$ will have no discernible effect on GDP growth
- The large increase in longevity outweighs the small decreases in the mean level of educational attainment and GDP per capita
- Well-being is higher than in the NOC in both the ICL and the ECL scenario
In India investments in reducing $PM_{2.5}$ will have no discernible effect on GDP growth.

The large increase in longevity outweighs the small decreases in the mean level of educational attainment and GDP per capita.

Well-being is higher than in the NOC in both the ICL and the ECL scenario.

Policies aiming at reducing $PM_{2.5}$ in India increase well-being and almost pay for themselves.
THANK YOU!

Contact
erich.striessnig@wu.ac.at
How does economic growth take place in SEDIM?

- One type of output, $Y_t$, is generated, using a Cobb-Douglas production function

$$Y_t = A_t \times L_t^\alpha \times K_t^{1-\alpha} \quad (1)$$

⇒ Anything that causes economic growth, has to do so by affecting one of these sources:

$L_t$...Effective Labor  
$K_t$...Capital Stock  
$A_t$...Total Factor Productivity  
($\alpha$...Output Elasticity of Labor)
Effective Labor, $L_t$

The workforce in SEDIM includes the full information on the population’s age- and educational attainment structure

$$L_t = \sum_{a=alfe(t)}^{alfx(t)} POP_{a,t} \times EU_{a,t}$$

(2)

- $alfe(t)$ ... age of labor market entry in year $t$
- $alfx(t)$ ... age of labor market exit in year $t$
- $POP_{a,t}$ ... population at age $a$ in year $t$
- $EU_{a,t}$ ... number of efficiency units embodied by worker of age $a$ in year $t$
Two types of capital holders

1. Consumers
2. Corporations or “wealthy individuals”
Two types of capital holders

1. Consumers
   - Income from labor and from capital assets
   - Save for life-cycle purposes
     - goal is to smooth consumption over their entire lifetime
     - **BUT:** suffer from imperfect foresight

2. Corporations or “wealthy individuals”
Capital, $K_t$

Two types of capital holders

1. Consumers
2. Corporations or “wealthy individuals”
Two types of capital holders

1. Consumers
2. Corporations or “wealthy individuals”
   - Receive income from capital investments
   - Non-life-cycle savers
     - investment rate depends on rate of return to capital
Capital, $K_t$

Two types of capital holders

1. Consumers
2. Corporations or “wealthy individuals”

The savings/investments of consumers and corporations interact to “buffer” the effect of aging.
Total Factor Productivity, $A_t$

SEDIM is a model of conditional convergence/divergence characterized by two gaps

1. a country’s “technological gap” with respect to the global technological leader
2. a country’s gap to its own “potential” level of $A_t$

Determining factors of a country’s “potential”, its “backwardness”, and the speed of catching-up include

- rate of capital formation
- educational attainment level of the workforce
- population age-structure
- the interaction of education and age-structure
- an economy’s level of “openness”
- the quality of political institutions, i.e., corruption, rule of law
Results: HDI

HDI by component relative to NOC, India, 2030