Simulations of Swiss climate policy with a computable general equilibrium model

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EPFL
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Outline

1. Background: What economists can contribute to climate issues
2. Our models, e.g. GEMINI-E3
3. Some results of our simulations
BACKGROUND: WHAT ECONOMISTS CAN CONTRIBUTE TO CLIMATE ISSUES
William D. Nordhaus

THE SVERIGES RIKSBANK PRIZE IN ECONOMIC SCIENCES IN MEMORY OF ALFRED NOBEL 2018

William D. Nordhaus
“for integrating climate change into long-run macroeconomic analysis”

Paul M. Romer
“for integrating technological innovations into long-run macroeconomic analysis”

THE ROYAL SWEDISH ACADEMY OF SCIENCES
Early contribution of Bill Nordhaus

CAn WE CONTROL CARBON DIOXIDE?

William D. Nordhaus

June 1975 WP-75-63

Father of the 2°C limit


Figure 1. Past and projected global mean temperature, relative to 1880-84 mean. Solid curve up to 1970 is actual temperature. Broken curve from 1970 on is projection using 1970 actual as a base and adding the estimated increase due to uncontrolled buildup of atmospheric carbon dioxide.
Integrated assessment

- Economic activities
- Utilisation of energy
- Emissions of GHG
- Impacts on ecosystems
- Impacts on the climate
- Impacts on welfare
- Economic impacts
- Corrective measures
Questions asked of economists

• What are the costs of climate change?
• What are the costs of mitigation?
• What is the optimal level of mitigation?
• How to allocate mitigation efforts across countries?
• How to allocate mitigation efforts over time?
• What policies can achieve target mitigation at least cost?
• How to best adapt to climate change?
Questions we were (and are) asked

• Is decarbonization possible?
• How much would it cost?
• What measures would it take?
• What have we achieved up to now?
• What will the economic impacts of climate change be?

⇒ Policy-driven research
What we are expected to provide

- Quantitative results
- Generally forward looking (predictive), but rarely also backward looking (counterfactual)
- Economywide, with detailed results for sectors or policy instruments
OUR MODELS, e.g. GEMINI-E3
Real flows

• Macroeconomic, e.g. Switzerland as an open economy part of the World
• Grand categories:
Monetary flows

- Monetary flows match the real flows of goods, services, labour, capital
- Prices are endogenous (except some world prices, e.g. world energy prices)
- Grand categories:

![Monetary Flow Diagram]

- Consumers (households)
- Public sector (government)
- Producers (firms)

Flow of Wages, interest, profit
Flow of Taxes – subsidies
Flow of Prices
Flow of Prices for goods and services
Flow of Exchange rate
Flow of Prices for G&S
Markets

- Production → supply of goods and services
- Consumption → final demand of G&S
- B2B → intermediate demand of G&S
- Markets: supply and demand for each G&S balance thanks to adjustments in prices; perfect competition
- Domestic and foreign G&S → international trade
- Markets for labour (→ wage), for capital (→ interest rate)
- Taxes, subsidies, regulation…

Catch a parrot and teach him to say ‘supply and demand’, and you have an excellent economist.

Popular joke in 19th century
GEMINI-E3

- **General Equilibrium Model of International-National Interactions between Economy, Energy and the Environment**
- **Sectoral and regional disaggregation, which can be simplified *ad hoc***

<table>
<thead>
<tr>
<th>Sectors</th>
<th>Geographic regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>Switzerland</td>
</tr>
<tr>
<td>Crude oil</td>
<td>European Union (28)</td>
</tr>
<tr>
<td>Natural gas</td>
<td>United States of America</td>
</tr>
<tr>
<td>Refined petroleum products</td>
<td>China</td>
</tr>
<tr>
<td>Electricity</td>
<td>India</td>
</tr>
<tr>
<td>Agriculture, forestry</td>
<td>Brazil</td>
</tr>
<tr>
<td>Energy intensive industries</td>
<td>Russia</td>
</tr>
<tr>
<td>Other goods and services</td>
<td>Central and South America</td>
</tr>
<tr>
<td>Land transport</td>
<td>Other Asian countries</td>
</tr>
<tr>
<td>Sea transport</td>
<td>Middle East</td>
</tr>
<tr>
<td>Air transport</td>
<td>Africa</td>
</tr>
<tr>
<td></td>
<td>Rest of the World</td>
</tr>
</tbody>
</table>
GEMINI-E3: Production

Output = \left[ \alpha_K K^\gamma + \alpha_L L^\gamma + \alpha_E \left( \alpha_{EL} EL^{\gamma_E} + \alpha_{EF} EF^{\gamma_E} \right)^{\gamma_E} \right]^{1/\gamma_E} + \alpha_I I^\gamma

The $\alpha$ are value shares adding up to 1, the $\gamma = (\sigma - 1)/\sigma$ determine the degree of substitutability, $K$ is capital, $L$ is labour, $EL$ is electricity, $EF$ is fossil energy, $I$ groups intermediate inputs.

Production function

- Constant elasticity of substitution (CES)
- Input-output matrix for intermediates
- Productivities (not shown) and elasticities of substitution
GEMINI-E3: Consumption

\[ \text{Welfare} = \left[ \sum_i \alpha_i G_i^\gamma \right]^{1/\gamma} \]

The \( \alpha \) are value shares adding up to 1, \( \gamma = (\sigma - 1)/\sigma \) determines the degree of substitutability, \( G_i \) are goods and services from sector \( i \)

Welfare function
- Constant elasticity of substitution (CES)
- Productivities and elasticities of substitution
- Serves to model consumer choices and to measure welfare changes
GEMINI-E3: costs

• Firms pay for their inputs and sell their products with a view to maximizing their profits; thus, they minimize their costs and respond to demand

\[ \text{Profit}_i = p_i \text{Output}_i - p_k K - p_L L - p_{EL} EL - p_{EF} EF - \sum_j p_j I_j \]

• Households decide on labour, savings and purchases of G&S with a view to maximizing their welfare; they must balance their purchases with their income minus savings and taxes

\[ p_K K + p_L L - \text{Taxes} = \sum_j p_j Q_j + \text{Savings} \]
Some results

EFFECTIVENESS OF THE CO₂ LEVY
In each sector $i$, a firm could be facing four different prices for its emissions of CO$_2$ depending on its situation: the CO$_2$ levy, the ETS price, a cost of abatement related to its offsetting commitment or nothing if its emissions are not covered by the CO$_2$ Act; hence, the average CO$_2$ price in sector $i$ is:

$$CO_2 \text{ price}_i = (1 - \alpha_i - \beta_i - \mu_i) \cdot CO_2 \text{ levy} + \alpha_i \cdot Price_{ETS} + \beta_i \cdot Price_{NonETS} + \mu_i \cdot 0$$
A rising tax does not guarantee a rising price

Consumer price for heating oil (extra-light)  
(with VAT and CO₂ levy)

Source: OFEN, Statistique globale suisse de l'énergie
Vielle, Marc, and Philippe Thalmann, "Updated emissions scenarios without measures, 1990-2035", Report for Federal Office for the Environment, Lausanne, 12 October 2017

Some results

SWISS CO$_2$ EMISSIONS WITH AND WITHOUT MEASURES, 1990-2035
How much of the change in CO$_2$ emissions is due to climate & energy policy?
How much is attributable to policy?

Energy-related CO$_2$ emissions in a scenario without measures and two scenarios with existing and announced measures (1990-2035)

![Graph showing CO$_2$ emissions from 1990 to 2035. The graph compares three scenarios: scenario without measures, scenario with existing measures, and scenario with existing measures plus announced measures. The x-axis represents years from 1990 to 2035, and the y-axis represents CO$_2$ emissions in Mio. t CO$_2$/a. The graph shows a decrease in emissions over time, with a -28% reduction by 2035.]
Effectivity of different components of energy and climate policy

Total reduction of CO₂ emission in scenario with decided measures compared to scenario without measures, by group of measures (1990-2035)

Fig. 2 of Vielle and Thalmann (2017)
Swiss climate policy under second CO$_2$ Law (2011, in force since 2013)

Second CO$_2$ Law
All greenhouse gases as in Kyoto Protocol
Target: minus 20% rel. 1990, purely domestic

GHG from energetic use of fossil vectors
They represent about 75% of all GHG emissions
Buildings -22%*
Transports 0%*
Industry -7%*

Other CO$_2$
about 10%

Other GHG
about 15%

*Intermediary objectives for 2015, variation relative to 1990: they have not been updated! Emissions from transports were still 3.3% above 1990 in 2018.
Policy measures in the 3 main areas…

**Transport**
- prescriptions on specific CO₂ emissions of new cars (target: 130 gram CO₂/km from 2015 on)
- required compensation by importers of transport fuels (max 10% of implicit emissions for max 5 ct/litre)

**Buildings** (housing and services)
- CO₂ levy on heating and process fuels (60 CHF/t in 2014-15, 84 CHF/t in 2016-17, 96 CHF/t in 2018-20, i.e. 25.6 ct/litre heating oil)
- Buildings Program

**Industry**
- tradable emissions permits (CH-ETS)
- exemption from tax in exchange for commitment (non-ETS)
Some results

LOWERING CO$_2$ EMISSIONS FROM THE SWISS TRANSPORT SECTOR

Include transport fuels under the CO\textsubscript{2} levy for cost efficient emissions reduction

- Uniform cost of carbon (2018-2019: 96 CHF/tCO\textsubscript{2}, only for thermal fuels, with exemptions for large emitters, so only 36% of total CO\textsubscript{2} emissions in 2018)

- When an overall reduction target is set, privileges for one sector imply a higher burden for the other sectors

- Example:

<p>| Table 3: CO\textsubscript{2} prices and welfare cost in 2050 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th></th>
<th>Ref.</th>
<th>Uni</th>
<th>Uni-ETS</th>
<th>Diff-ETS</th>
<th>Uni</th>
<th>Uni-ETS</th>
<th>Diff-ETS</th>
<th>Uni</th>
<th>Uni-ETS</th>
<th>Diff-ETS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average CO\textsubscript{2} price</td>
<td>82</td>
<td>652</td>
<td>637</td>
<td>746</td>
<td>1089</td>
<td>1010</td>
<td>1255</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-ETS sector</td>
<td>252</td>
<td>652</td>
<td>193</td>
<td>196</td>
<td>1089</td>
<td>174</td>
<td>176</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-transport fuel</td>
<td>0</td>
<td>652</td>
<td>738</td>
<td>419</td>
<td>1089</td>
<td>1331</td>
<td>794</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-thermal fuel</td>
<td>121</td>
<td>652</td>
<td>738</td>
<td>1676</td>
<td>1089</td>
<td>1331</td>
<td>3175</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost (in% of household cons.)</td>
<td>0.74%</td>
<td>0.85%</td>
<td>1.01%</td>
<td>1.33%</td>
<td>1.60%</td>
<td>1.88%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Are high CO₂ levy rates feasible?

<table>
<thead>
<tr>
<th>CHF/t CO₂</th>
<th>Tax (francs/l)</th>
<th>Yearly rise from 2020 to 2050 (ct./l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gasoline</td>
<td>heating oil</td>
</tr>
<tr>
<td>96</td>
<td>0.224</td>
<td>0.254</td>
</tr>
<tr>
<td>100</td>
<td>0.233</td>
<td>0.265</td>
</tr>
<tr>
<td>652</td>
<td>1.519</td>
<td>1.728</td>
</tr>
<tr>
<td>1089</td>
<td>2.537</td>
<td>2.886</td>
</tr>
</tbody>
</table>

Vers une taxe carbone de 1,70 franc par litre?

Des chercheurs de l'EPFL ont calculé le montant le plus efficace pour atteindre les objectifs de l'Accord de Paris.
A high tax on a small base does not hurt much

Figure 3: Share of each vehicle type in distance traveled in percentage in 2050 - Cars
Some results

DECARBONISATION PATHWAYS FOR SWITZERLAND
Decarbonisation pathways for Switzerland

In parallel with *Deep Decarbonization Pathways Project* (DDPP) launched in October 2013 in view of COP21 (Paris)

Deep Decarbonization Pathways Project (2015), Pathways to deep decarbonization 2015 report - executive summary, SDSN – IDDRI, Fig. 2
Decarbonisation pathways for Switzerland

- Ambitious but realistic target: 1-1.5 tCO$_2$ eq/capita in 2050 (all GHGs without air transport and without LULUCF)
- Same target as the "NEP" scenario of the Energy Perspectives (Prognos, 2012) and as the Swiss INDC for COP21
- This target was seen as compatible with $+2^\circ$ warming
- Imagine and calculate the instruments necessary to achieve this: use existing instruments plus generalised CO$_2$ levy
Deep decarbonisation pathways (for max +2°)

needed for max +1.5°

Emissions [Mio. t CO₂eq]

Level 1990

-30% domestic

-20% international

-67%

Schäppi et al. (2016)
How to get to 1t CO$_2$/capita in 2050

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$<em>2$ levy (CHF$</em>{2013}$/tCO$_2$)</td>
<td></td>
<td></td>
<td></td>
<td>177</td>
</tr>
<tr>
<td>Price of CO$<em>2$ certificates (CHF$</em>{2013}$/tCO$_2$)</td>
<td></td>
<td></td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>Tax on gasoline and diesel (CHF$_{2013}$/l)</td>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td>Same CO$<em>2$ levy on all fossils (CHF$</em>{2013}$/tCO$_2$)</td>
<td></td>
<td>88</td>
<td>189</td>
<td>511</td>
</tr>
<tr>
<td>Social cost (% household consumption, relative to reference scenario)</td>
<td>0.11</td>
<td>0.42</td>
<td>0.78</td>
<td></td>
</tr>
</tbody>
</table>

Vielle et al. (2016). Scenario with induced technical progress (CCS is allowed)

511 CHF/tCO$_2$ with emissions of 1 tCO$_2$/capita on average in 2050 is comparable to 128 CHF/tCO$_2$ for current emissions of 4 tCO$_2$/capita

511 CHF/tCO$_2$ amount to 1.35 CHF/litre heating oil, which are added to the expected pre-CO$_2$-levy price of 1.40 CHF/litre in 2050
## Kaya decomposition of central DDP

### Mean annual rate of change per decade

<table>
<thead>
<tr>
<th></th>
<th>2010-2020</th>
<th>2020-2030</th>
<th>2030-2040</th>
<th>2040-2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population</strong></td>
<td>+1.6%</td>
<td>+0.4%</td>
<td>+0.3%</td>
<td>+0.2%</td>
</tr>
<tr>
<td><strong>Reference scenario (existing policies)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDP per capita</td>
<td>+0.1%</td>
<td>+1.3%</td>
<td>+1.2%</td>
<td>+0.9%</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>-2.8%</td>
<td>-1.0%</td>
<td>-0.6%</td>
<td>-1.2%</td>
</tr>
<tr>
<td><strong>Decarbonisation scenario with induced technical change</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDP per capita</td>
<td>-0.1%</td>
<td>+1.0%</td>
<td>+0.9%</td>
<td>+0.7%</td>
</tr>
<tr>
<td>Energy intensity</td>
<td>-2.7%</td>
<td>-2.8%</td>
<td>-2.8%</td>
<td>-2.9%</td>
</tr>
<tr>
<td>Carbon intensity</td>
<td>-0.7%</td>
<td>-1.1%</td>
<td>-1.6%</td>
<td>-3.1%</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>-1.9%</td>
<td>-2.5%</td>
<td>-3.4%</td>
<td>-5.1%</td>
</tr>
</tbody>
</table>

Vielle et al. (2016, unpublished table)
All sectors must contribute

CO\textsubscript{2} emissions (with international aviation, Mt)

Decarbonisation scenario
with induced technical progress

Reference scenario

Vielle et al. (2016, Fig. 2 + 15)
The cost depends on technological progress and what the ROW does

<table>
<thead>
<tr>
<th>Swiss deep decarbonization scenario</th>
<th>Social cost in 2050 (% household consumption, relative to reference scenario)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central (with CCS and induced technical progress)</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Central without CCS</td>
<td>-1.1%</td>
</tr>
<tr>
<td>Central without induced technical progress</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Central with international DDP</td>
<td>-1.3%</td>
</tr>
</tbody>
</table>

Vielle et al. (2016)
Take home messages

• Switzerland can reduce its energy CO\textsubscript{2} emissions to 1 t/capita and its total GHG emissions to 1.5 tCO\textsubscript{2}eq/capita by 2050

• This would cost as much, in terms of welfare, as if households had to reduce their overall consumption by 1%

• Non-monetary benefits (e.g. less air pollution) are not yet taken into account

• The building sector will play a central role in decarbonisation, encouraged by an increasingly high price of fossil fuels

• Other sectors (mobility) must also contribute

• For the other countries, comparable scenarios have been calculated and proven
FINAL COMMENTS
The longer we wait, the greater the effort needed
What speaks for full decarbonisation by 2050

• GHG emissions decline (but not fast enough) for several reasons, even without strengthening climate and energy policy: technical progress, EU policies, slowing growth, energy prices
• Welfare costs are moderate, even with high CO$_2$ tax rates
• The CO$_2$ tax could be kept lower by using its revenues to facilitate substitutions and strengthen effects
• No one modelled full decarbonisation of Switzerland yet!
Conclusions

• Pushing firms and households to decarbonize through price signals will call for high taxes … hardly acceptable, hardly doable (even if actual welfare cost is small)

• A 'New Climate Deal' is needed

• Example: decarbonisation of Swiss railway transportation between 1918 and 1950!
Thank you for your attention

Even with a small bucket:
everybody, every country must contribute!