Discussion of "Integrated Assessment in a Multi-region World with Multiple Energy Sources and Endogenous Technical Change" by John Hassler, Per Krusell, Conny Olovsson and Michael Reiter

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Short summary

- IAM with multi-regions (5), multiple energy sources (3) and DTC:
  - $\longrightarrow$ This is going to be a complicated, black-box model with numerical results but little economic intuitions...
    - It is not! The paper strikes a really nice balance between richness and simplicity (in part because they use Golosov et al., 2014).
- Goal: calibrate the model and analyze the impact of various policies (a positive paper) and then investigate the role of (endogenous) technological change.
- Some quantitative results:
  - Taxing coal but not oil is enough. Coal is in fully elastic supply (given extraction cost), while oil is in fixed supply and quantitatively less important.
    - Oil taxes mostly have redistributive effects.
  - Taxing carbon only in Europe is not enough.
- Focus on DTC part.

The model (1)

- Final good produced according to: $Y_{i,t} = A_{i,t} L_{i,t}^{1-\alpha-\nu} K_{i,t}^{\alpha} E_{i,t}^{\nu}$ with energy produced as:

$$E_{i,t} = \left(\lambda_1 \left(e_{1,t}\right)^{\rho} + \lambda_2 \left(e_{2,t}\right)^{\rho} + \lambda_3 \left(e_{3,t}\right)^{\rho}\right)^{\frac{1}{\rho}}$$

  - $e_{1,t}$ is oil bought from the oil producing country at a price $p_{1,t}$.
  - $e_{2,t}$ is coal locally extracted at cost $p_{2,t}$ (in units of final good) and $e_{3,t}$ is green energy produced at cost $p_{3,t}$.
  - Not an uncommon assumption: but no difference here between the resource and its energy services.
  - Elasticity of substitution $\sigma = 1/\left(1-\rho\right)$.

The model (2)

- Coal demand obeys:

$$\frac{e_{2,t}}{e_{3,t}} = \left(\frac{\lambda_2}{\lambda_3} \frac{p_{3,t}}{(1+\tau_{2,t})\, p_{2,t}} \right)^{\frac{1}{1-\rho}} \text{ and } e_{2,t} = \left(\frac{\lambda_2 P_t}{(1+\tau_{2,t})\, p_2} \right)^{\frac{1}{1-\rho}} E_t\left(P_t\right)$$

  - A tax on coal energy τ_2, or a relative increase in the price of coal ($p_{2,t}/p_{3,t}$ increases) both lead to use relatively more green energy relative to coal energy.
  - The two have a different impact on total energy demand though (scale effect).
    - A decrease in the price of green energy alone leads to an increase in coal consumption when the two inputs are complements ($\rho < 0$).

DTC with ad-valorem taxes (1)

- For simplicity, ignore oil and assume 1 country. Then the energy sector solves:

$$\min P_t = \left(\lambda_2^{\sigma}\left(1+\tau_2\right)^{1-\sigma} p_2^{1-\sigma} + \lambda_3^{\sigma} p_3^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

$$\text{st } p_{2,t}^{\varepsilon_2} p_{3,t}^{1-\varepsilon_2} = \exp\left(-a\right) \overline{p}_{2,t-1}^{\varepsilon_2} \overline{p}_{3,t-1}^{1-\varepsilon_2} = \exp\left(g_Y - a\right) p_{2,t-1}^{\varepsilon_2} p_{3,t-1}^{1-\varepsilon_2}$$

  - with g_Y the growth rate of output. If $g_Y = a$ then the geometric average of energy prices is constant.
  - This is what one obtains with a fixed mass of scientists allocated to improve coal extraction or green energy with $A_{z,t} = e^{\varepsilon_z S_z} A_{z,t-1}$.

- Assume the two inputs are complements ($\sigma < 1 \Leftrightarrow \rho < 0$). Then P_t is lower when $\lambda_2^{\sigma}\left(1+\tau_2\right)^{1-\sigma} p_2^{1-\sigma}$ and $\lambda_3^{\sigma} p_3^{1-\sigma}$ are close to each other.

DTC with ad-valorem taxes (2)

- If $\varepsilon_2 = 1/2$ (and $\sigma < 1$) so that improving coal tech. is as easy as improving clean tech, P_t is minimized when

$$\frac{\lambda_2^{\frac{\sigma}{1-\sigma}} (1+\tau_2) p_2}{\lambda_3^{\frac{\sigma}{1-\sigma}} p_3} = 1 = \left(\frac{\lambda_2^{\frac{\sigma}{\sigma-1}} e_2}{\lambda_3^{\frac{\sigma}{\sigma-1}} e_3} \right)^{-\frac{1}{\sigma}}.$$

  - Innovation favors the more backward sector, so that the effective prices are equal in the long-run.
- If $\varepsilon_2 \neq 1/2$ ($\sigma < 1$), the innovation technology for both techn. is not the same but $(1+\tau_2) p_2 / p_3$ is still constant.
  - τ_2 has no long-run effect on relative demand for green and coal energy.
- If the two inputs are substitute ($\sigma > 1$), P_t is lower when $\lambda_2^{\sigma} (1+\tau_2)^{1-\sigma} p_2^{1-\sigma}$ and $\lambda_3^{\sigma} p_3^{1-\sigma}$ are far from each other.
  - Innovation is "bang-bang" and favors the most advanced sector.
  - A change in τ_2 may redirect innovation toward green tech. (AABH).

DTC with unit taxes

- Under the same innovation constraint, the energy sector solves:

$$\min P_t = \left(\lambda_2^{\sigma}\left(\tau_2 + p_{2,t}\right)^{1-\sigma} + \lambda_3^{\sigma} p_{3,t}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}.$$

- Therefore, for $\sigma < 1$, you would want to equalize $\lambda_2^{\sigma}\left(\tau_2 + p_2\right)^{1-\sigma}$ and $\lambda_3^{\sigma} p_3^{1-\sigma}$ but innovation allows to reduce p_2 not $\tau_2 + p_2$.
- More specifically, if $p_{2,t}, p_{3,t} \longrightarrow 0$ and $\tau_{2,t} = \tau_2$, we get:

$$\frac{\partial \ln P_t}{\partial \ln p_{2t}} \approx \frac{p_{2,t}}{\tau_2} \text{ and } \frac{\partial \ln P_t}{\partial \ln p_{3t}} \approx \frac{\lambda_3^{\sigma} p_{3,t}^{1-\sigma}}{\lambda_2^{\sigma} \tau_2^{1-\sigma}}$$

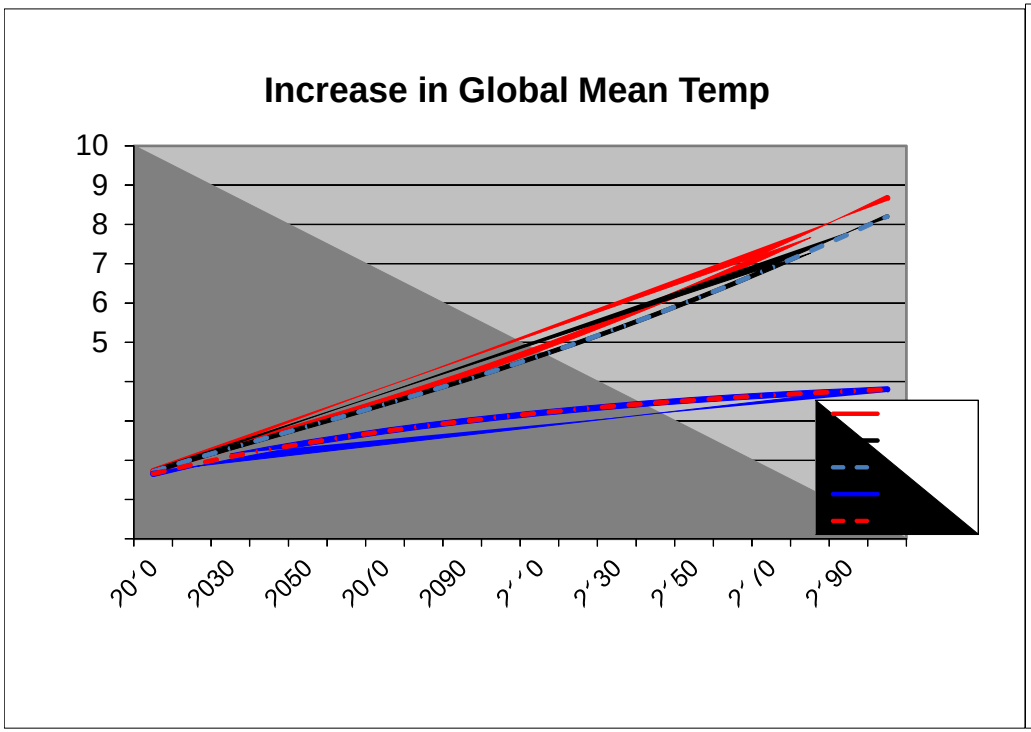
  - The marginal return on an innovation in coal decreases faster than that of an innovation in green technologies.
  - A higher τ_2 leads to higher p_2 (a higher $p_2 + \tau_2$) and lower p_3.
- A constant τ_2 may redirect innovation toward green instead of coal for any σ.
  - The welfare consequences are different: if $\sigma < 1$, growth is permanently reduced.

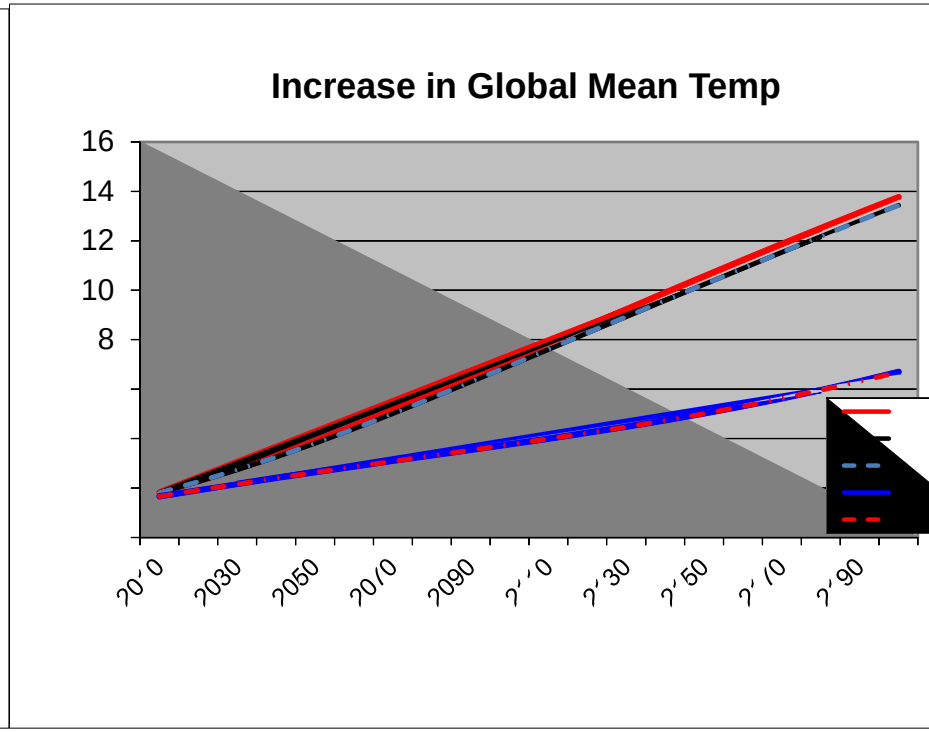
What is the elasticity of substitution?

- HKOR use $\sigma = 0.95 < 1$: coal, oil and green technologies are gross complement. This is an estimate from a meta-study by Stern (2010). Some predictions of $\sigma < 1$:
  - Fossil fuels are necessary in energy production; if their production is bounded, so will energy services be;
  - But so are green technologies: hence there should have been no energy produced before solar, wind and nuclear became available;
  - Even without taxes, private R&D would have ensured that green technologies catch up very quickly to fossil fuels...

  $\rightarrow$ A realistic **long-run** elasticity of substitution should be greater than 1.
- Papageorgiou, Saam and Schulte (Restat, 2016) aim to estimate long-run elasticity for macro.
  - They use cross-country, cross-industry panel data.
  - Elasticity of substitution between green tech. and fossil fuels in electricity production of 2 (using installed capacity instead of fuels) and an elasticity between electricity and (non-electric) fossil fuel energy of 3.

Temperature increase and elasticity





Other comments

- Technological progress in green technologies and extraction technologies but not in energy efficiency or fossil-fuel energy production.
- Oil is in fixed supply. In reality, the supply depends on discoveries, R&D investments, etc... which may be affected by taxes.
- A few comments on the calibration:
  - λ is calibrated by looking at world production and prices. Then relative prices are somewhat arbitrarily adjusted for each country.
  - Price of green tech. is fixed to be = price of oil ... quite arbitrary. Why not use level cost estimates?
  - It should be possible to get price / production data for each region and estimate a best fit for $\lambda's$.

  $\rightarrow$ Model is sufficiently detailed that the numbers may have value beyond illustration.
  - China and Africa could be calibrated away from steady-state.
- Risk!