# Discussion of:
# 'An extended Integrated Assessment Model for mitigation and adaptation policies of climate change' (and a bit more)

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# Summary

Two papers:

1. 'An extended Integrated Assessment Model for mitigation and adaptation policies of climate change'
    - Main focus: study the use of public investment expenditure across three types of capital stocks
    - Public investment is financed through tax revenues (not debt)
    - Emissions produced by fossil fuel extraction, but no damage function
2. 'Financing climate policies through carbon taxation and climate bonds - Theory and empirics'
    - Main focus: study the interaction between climate bonds and carbon pricing (carbon pricing by itself is not enough)
    - Much simpler structure
    - Damage function impacting output
    - Abatement financed through climate bonds and/or carbon pricing
    - The issuance of climate bonds lead to an increase in public debt, repaid in a second stage through tax revenues

# Outline of my discussion

Focus on the first paper, with some 'interventions' from the second where appropriate:

- Explicitly introduce a renewable energy capital stock
- Modify the function of mitigation public capital, currently CCS
- Introduce a damage function to study adaptation
- Allow for new borrowing in public debt dynamics
- Modify the production function to limit substitutability
- Other minor comments

# Four types of capital stocks

1. $K$: Private capital stock, should include renewable energy production
2. $K_{G,Trad}$ ($\nu_1 g$): A 'traditional' public capital that enters the production function as a productivity-augmenting factor (infrastructure)

$$Y = K_{G,Trad}^{\beta} A (A_K K + A_u u)^{\alpha}$$

3. $K_{G,Adapt}$ ($\nu_2 g$): An 'adaptation' public capital that enters the utility function as a positive argument (sea walls)

$$U = \frac{\left( C(\alpha_2 e_P)^{\eta} (M - \tilde{M})^{-\epsilon} K_{G,Adapt}^{\omega} \right)^{1-\sigma} - 1}{1-\sigma}$$

4. $K_{G,Mitig}$ ($\nu_3 g$): A 'mitigation' public capital that reduce $CO_2$ atmospheric concentration (really: $CO_2$-removing CCS technology)

$$\dot{M} = \gamma u - \mu (M - \kappa \tilde{M}) - \theta K_{G,Mitig}^{\phi}$$

# Capital dynamics

Private capital:

$$\dot{K} = Y - C - e_P - (\delta_K + n) - u\psi R^{-\tau}$$

Total public capital:

$$\dot{K}_G = I_{KG} + i_F + (\delta_G + n)K_G$$

where $I_{KG}$ is a fixed proportion $\alpha_1$ of tax revenues $e_P$:

- $\alpha_1 e_P$ (0.1) Public capital accumulation
- $\alpha_2 e_P$ (0.7) Social transfers (enters utility function)
- $\alpha_3 e_P$ (0.1) Administrative overhead (goes where?)
- $\alpha_4 e_P$ (0.1) Debt service

# Critical issues

This structure creates some confusion:

- Combining 'normal' capital and renewable energy capital makes it Infeasible to distinguish capital investment paths
- Mitigation is reduced to yet-to-come CCS (also: would CCS be the result of public or private investment?)

Some possible improvements:

- Explicitly model renewable energy capital ($K_{Ren}$)
- Introduce a non-CCS type of mitigation public capital that could play a similar role to $K_{G,Trad}$ for $K$

# An alternative specification? (I)

Output is produced combining private capital and energy:

$$Y = K_{G,Trad}^{\beta} A (A_K K + A_E E)^{\alpha}$$

Energy can be produced either through non-renewable or renewable energy sources:

$$E = E_{NR} + E_R$$

where $E_{NR}$ is just a linear function of extracted fossil fuels

$$E_{NR} = \upsilon u$$

and $E_R$ is produced using a stock of 'green' capital (wind farms, etc.) and the stock of public mitigation capital (electricity grid, network of battery charging stations, etc.)

$$E_R = K_{G,Mitig}^{\beta} A_{Ren} K_{Ren}^{\alpha}$$

# An alternative specification? (II)

$K_{Ren}$ motion depends on investment

$$\dot{K}_{Ren} = I_{Ren} + (\delta + n) K_{Ren}$$

where $I_{Ren}$ is a proportion $\zeta$ of total private investment

$$I_{Ren} = \zeta I_{Tot}$$

with $\zeta$ new endogenous variable.

- Control variables should remain three ($C$, $e_P$, $\zeta$), with $\zeta$ instead of $u$ if we assume that fossil energy $E_{NR}$ is a residual variable (i.e. first firms use all available $E_R$, then, if needed, they extract fossil fuels).

# Adaptation capital

Adaptation capital enters the utility function directly:

$$U = \frac{\left(C(\alpha_2 e_P)^{\eta}(M - \tilde{M})^{-\epsilon} K_{G,Adapt}^{\omega}\right)^{1-\sigma} - 1}{1-\sigma}$$

This is quite counter-intuitive: why should individuals care directly about sea walls?

In the climate bonds paper:

$$Y_{net} = (a_1 M^2 + 1)^{-\psi} Y_{gross}$$

Use the same specification in the first paper as well?

$$Y_{net} = \frac{(a_1 M^2 + 1)^{-\psi}}{f(K_{G,Adapt})} Y_{gross}$$

# Public debt

- Public debt follows the following dynamics:

$$\dot{b} = (\bar{r} - n)b - \alpha_4 e_P$$

- There is no real new debt issuance. There is an initial stock ($b(0) = 0.8$) that increases if interest payments are higher than the share of tax revenues allocated to debt service ($\alpha_4 e_P$).
- In the climate bonds paper, instead, public debt increases if abatement $A$ is carried out, and there is no repayment:

$$\dot{B} = rB + A$$

- Take the best of two worlds?

# An alternative specification? (III)

- $e_P$ is set as a fixed proportion of output ($e_P = \tau Y$) instead of being endogenous
- Total investment in public capital $I_{KG}$, instead of being a fixed proportion of tax revenues ($I_{KG} = \alpha_1 e_P$), becomes endogenous. In case of 'excess' public capital investment ($\alpha_1 e_P < I_{KG}$) new public debt is emitted.

$$\dot{b} = (\bar{r} - n)b - \alpha_4 e_P + (I_{KG} - \alpha_1 e_P)$$

- Depending on how $K_G$ is allocated one can distinguish 'green' ($I_{KG,Mitig} + I_{KG,Adapt}$) from 'regular' bonds ($I_{KG,Trad}$), and possibly study policies introducing regulations incentivising the former.

# Simulations

Striking result: Production takes place without any explicit form of energy ($u = 0$) for most of the simulation time. Even if $K$ did include renewable energy capital there is no way the transition could happen so quickly

- Is this due to the production function?

$$Y = K_{G,Trad}^{\beta} A (A_K K + A_u u)^{\alpha}$$

- CES production function to limit substitutability?

$$Y = K_{G,Trad}^{\beta} \left( a (A_K K)^{\alpha} + (1-a)(A_u u)^{\alpha} \right)^{\frac{1}{\alpha}}$$

Other issues:

- Why the terminal date at 25? What happens after?
- What brings $K$ down? Not debt, as debt service remains a fixed share $\alpha_4$ of tax revenues. Is it the terminal constraint ($K(T) = 3$)? What happens if this is removed?
- Welfare improvement with endogenous (vs exogenous) $\nu$: obvious result? Relevance of strategy with fixed $\nu$?

# Conclusions

Value added of the papers:

- introduce public capital stock dynamics into IAM framework (mitigation + adaptation).
- Introduce public debt dynamics

Possible changes:

- Explicitly distinguish between $K$ and $K_{Ren}$(possibly with mitigation public capital as productivity-enhancing factor)
- Introduce a damage function to study adaptation (like in climate bonds paper)
- Allow for new borrowing in public debt dynamics (like in climate bonds paper)
- Modify the production function to limit substitutability
- Eliminate the strategy with exogenous $\nu$
- Simplify the utility function (only $C$ and $M$?)

# Additional minor comments

- It's confusing to have stock variables denoted by lower-case letters. Transform $b$ and $g$ in $B$ and $G$ (or even better, $K_G$)
- Is it necessary to have population growth $n$ at all?
- Initial CO2 concentration might be too high compared to data ($M(0) \approx 1.2$)
- Redundancy of $A$ term in $K$ production function? There's public capital already
- Add references to public capital growth literature (Turnovsky 1997, Chatterjee et al. 2003, Agenor 2010, etc.)
- Role of opportunity cost in $\dot{K}$ equation?
- Who owns public debt? Unclear at the moment.
- Could $r$ be a function of $b$ instead? Growing public debt leads to higher interest rates