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To the members of the Editorial Board of the
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Re: Prof. Richard Tol's unfounded assertions about supposed flaws in the REMIND model

Dear Editors,

An entry on Prof. Richard Tol's blog[1] regarding our recently accepted article on the "Economics of nuclear power and climate mitigation policies" (Bauer, Brecha, Luderer 2012) has come to our attention. In this piece, Prof. Tol claims to have found fundamental flaws in the REMIND model, which was used for the analysis underlying the paper.
The allegations made by Prof. Tol regarding REMIND are false and unfounded. To preempt any potential concerns or doubts caused by his allegations, we would like to shed light on the relevant underlying model framework and assumptions, and how these contradict Prof. Tol's assertions. The critique by Prof. Tol can be summarized in the following six points, which we address individually in the following.

1. *Tol: "They modeled a closed system as if it were open.[…] Money disappears from Earth and reappears later".*

   This statement is false. It would be correct if the global sum of goods imported by regions could exceed the sum of exports. In REMIND, however, this is not possible because for all time steps t and all goods $\underline{i}$ trade is constrained by global trade balances of the form

$$\sum_{r} \left(X_i(r,t) - M_i\,(r,t) \right) = 0 \qquad (1)$$

   where $X_i\,(r,t)$ are exports of good i by region r, and $M_i\,(r,t)$ are imports.

[1] http://richardtol.blogspot.co.uk/2012/08/the-economics-of-nuclear-power-and.html

Spending is limited by the budget constraint, which holds for each region and time step:

$$Y(r,t) - X_G(r,t) + M_G\,(r,t) \;\geq C(r,t) + I(r,t) + E(r,t) \qquad (2)\,,$$

which states that for each region and time period, total macro-economic output Y net the effects of trade in the generic goods (export X_G and import M_G) cannot be less than the expenditures for consumption C, macro-economic investments I and expenditures E for investments and operations in the energy system as well as resource extraction. While each region is an open system (it can import more than it exports), the global system is closed. This becomes clear from combining the sums of the regional budget equations with the international trade balance equation, which yields a global version of the budget constraint:

$$\sum_r Y(r,t) \geq \sum_r \big(C(r,t) + I(r,t) + E\,(r,t)\big) \qquad (3)$$

The resulting condition ensures that the global total output cannot be less than the sum of consumption, macro-economic investments, and energy system expenditures. Consequently, the system is closed, and there is no such thing as "money disappearing and reappearing later".

2. *Tol: "Its capital account is zero by construction, a peculiar assumption, and its current account is balanced over time rather than at each point in time"*

   The capital account is the counterpart of the current account, and thus is non-zero for individual regions with non-zero current account. In REMIND, the regional balances of trade

$$\sum_i p_i \left(X_i(r,t) - M_i\,(r,t)\right) \overset{i.g.}{\neq} 0 \qquad (4)$$

with p_i as the price of good i, are non-zero in general. The global trade balances as formulated in (1) ensure that the sum of regional current accounts is zero, i.e., regions with a current account deficit are balanced by the regions with a current account surplus. Debts and assets which accrue from trade are balanced intertemporally in REMIND. This is ensured by the intertemporal budget constraint:

$$\int_0^T dt \;\sum_i \pi_i(t) \left(X_i(r,t) - M_i\,(r,t)\right) = 0 \qquad (5)$$

where the integration runs until the end of the time horizon *T,* and present value prices $\pi_i(t)$ are used, such that discounting and interest payments are implicit.

3. *Tol: "(Bauer et al. 2012) write that they use 'Negishi weights' to balance the current account over time. This is plain nonsense. […] (Bauer et al. 2012) did not use Negishi weights – they just called it that. […] Therefore, their solution does not represent a market equilibrium."*

   (Negishi 1960, 1972) introduced these weights to find a competitive equilibrium in international trade. He demonstrated that with a particular set of (regional) welfare weights the solution of the welfare-maximizing problem is equivalent to the competitive market equilibrium. The crucial condition for this equivalence is that the consumers (the representative agents) meet their budget constraints. In the intertemporal setting, where banking and borrowing over time is allowed, this translates to the condition that the intertemporal budget be balanced. The selection of welfare weights in REMIND is an iterative process, which ensures that regions meet their inter-temporal budget constraint, cf. Eq. (5). Thus REMIND identifies a planner solution that corresponds to the market equilibrium under the assumption that externalities (such as the climate constraint) are internalized. The approach applied in REMIND represents an intertemporal extension of the original Negishi approach. It is well established in the literature by Manne and Rutherford (1994) and used by other models like MERGE (Manne et al. 1995) and RICE (Nordhaus and Yang 1996)[2].

4. *Tol: "This could have been avoided if the editor had insisted that the economic part of the model be published in an economics journal first."*

   Prof. Tol insinuates that the REMIND model has not yet been published in an economic journal. This is not the case. The model and its results are presented in economic journals (*Energy Journal*, Leimbach et al. 2010 and Edenhofer et al. 2010; *Energy Economics*, Luderer et al. 2012; as well as the interdisciplinary journals *Climatic Change* (Bauer, Baumstark, et al. 2012; Luderer, Bosetti, et al. 2012), Environmental Modeling and Assessment (Leimbach et al. 2010) and *Energy Policy* (Lüken et al. 2011). Moreover, specific methodological details on hard-linking the energy system model with a macro-economic model have been discussed in the *Journal of Computational Management Science* (Bauer et al. 2008).

[2] In RICE, additional constraints on exports, net foreign assets and current account deficits are introduced to limit capital flows between regions.

5. *Tol: "There are more humdrum errors too. The cost estimates of emission reduction are biased downwards. If you allow rapid technological progress through learning-by-doing in renewable energy but not in fossil fuels*."

   We disagree on the statement that mitigation cost estimates in REMIND are "biased downwards". REMIND represents learning-by-doing for wind and solar power technologies. Learning curve effects for these technologies are well established in the empirical literature (Fischedick et al. 2011). In REMIND, we describe technological progress in other technologies (such as coal power plants) is described via exogenous changes of techno-economic parameters. Technology availability and energy demand are the most important determinants of mitigation costs. A considerable number of mitigation options in energy supply, including, for example, bioenergy with CCS, are represented in REMIND. Our mitigation cost estimates are well within the range of results from other energy-economy models.

6. *Tol: "The main findings have been known for years."*

   We do not agree. We are aware of only a few studies that have explored the role of nuclear power in climate policy by comparing scenarios with restricted expansion of nuclear to climate policy scenarios with unconstrained nuclear expansion. These studies are cited in our literature review. None of them have explored the dimension of early decommissioning of nuclear power plants, nor the combined effects of restrictions in nuclear investments and premature decommissioning. Our study goes well beyond previous work by exploring the economic implication of nuclear power policies along the dimensions of restrictions on investments into new capacities, premature decommissioning of existing nuclear capacities and climate mitigation targets.

In summary, we conclude that the points made by Prof. Tol are unfounded. We are offering these explanations to vigorously defend the scientific integrity of our work that was questioned by Prof. Tol's false allegations. We thank the editors for the professional handling of this matter.

Sincerely,

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Senior Researcher

On behalf of the team of authors
Nico Bauer, Robert J. Brecha, Gunnar Luderer

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