AN INTEGRATED ASSESSMENT MODEL OF ECONOMY-ENERGY-CLIMATE – THE MODEL WIAGEM: A COMMENT

Roberto Roson[a,b] and Richard S.J. Tol[c,d,e]

[a] *Ca'Foscari University of Venice, Venice, Italy*
[b] *Fondazione Eni Enrico Mattei, Venice, Italy*
[c] *Centre for Marine and Climate Research, Hamburg University, Hamburg, Germany*
[d] *Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands*
[e] *Center for Integrated Study of the Human Dimensions of Global Change, Carnegie Mellon University, Pittsburgh, PA, USA*

May 28, 2003

Working Paper FNU-26

Economic assessments of the impacts of climate change are rare. Even rarer are papers on the higher order economic impacts. The paper by Claudia Kemfert (2002) is therefore welcome. Most economic impact studies use direct costs as an approximation of welfare losses. According to the direct cost method, a welfare loss is approximated by price times quantity, where the quantity is the physical impact of climate change (see Pearce *et al.*, 1996, and Smith *et al.*, 2001, for an overview). The direct cost method ignores that the impact may change the price (the partial equilibrium effect), that changes in one market may have effects on other markets (the general equilibrium effect), and that climate change may alter investments (the growth effect). Using a dynamic computable general equilibrium model, Kemfert is able to look at all economic effects of climate change impacts on nature, human health, forestry, water resources, and energy consumption.

Only four other papers use a similar methodology. Scheraga *et al.* (1993) use now outdated climate change scenarios and climate change impact studies, and only sketch the assumptions and results. The papers by Darwin *et al.* (1995) and Darwin and Tol (2001) are limited to the impacts on agriculture and coastal zone, respectively; the model used there is a static CGE. Deke *et al.* (2001) come closest to Kemfert, but only look at agriculture and coastal protection. Kemfert clearly improves on these papers.

Kemfert proceeds as follows. She takes a selection of the welfare losses estimated by Tol (2002a,b), and runs part of his model with her scenarios of population, income and climate. She sums the impacts, and calibrates a power function to the results (Equation 3.14).

Figure 1 compares Kemfert's "approximation" (read from her Figure 8 and inferred from her Table 11; the latter is probably what she used, see below) and Tol's original model (run with the IS92a scenario and the climate sensitivity lowered to 0.6 to reproduce the reported warming in Kemfert's Figure 6). It is clear that Kemfert's impacts and Tol's differ substantially. Indeed, if we inspect Kemfert's model a bit closer, differences emerge. For instance, Kemfert's *extrapolating* function (3.11) for "mortality" corresponds to Tol's separate *intrapolating* functions for cardiovascular and respiratory mortality. In equations (3.12) and (3.13), Kemfert reinterprets Tol's changes in *welfare* due to changes in energy consumption as changes in energy *demand*. As Kemfert is silent about the reasons for these changes – indeed, she does not alert the reader to the fact that changes have been made – we do not pursue this particular point further.

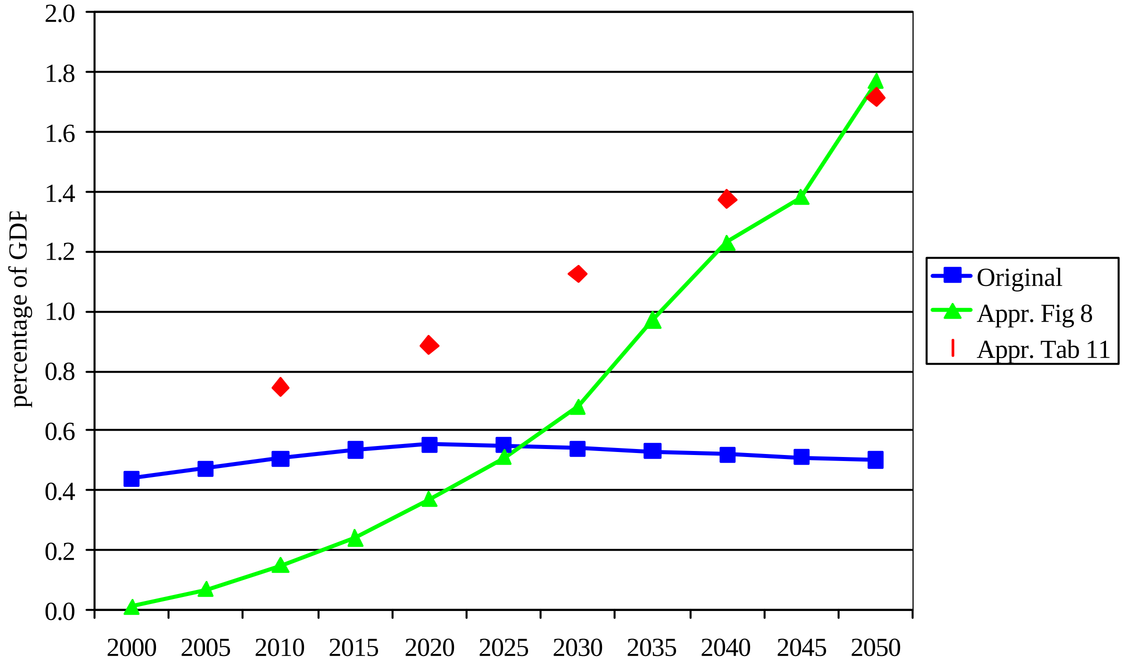

Figure 1. Impacts of climate change according to Tol's original model and Kemfert's approximations according to her Figure 8 and Table 11.

Kemfert reports climate change impacts of around 1.7% of GDP for a global warming of 0.25 C. Let's follow Kemfert in assuming that impacts are proportional to $áT^{â}$ where T is the global mean temperature and $á$ and $â$ are parameters; 0.5 > $â$ > 1.5. The impact of climate change for a 2.5 C warming, say due to a doubling of the atmospheric concentration of carbon dioxide, would be 17.0% of GPD if $â$ = 1.0 (5.4% if $â$ = 0.5; 53.8% if $â$ = 1.5). These numbers are substantially higher than the even the maximum numbers reported in the Second and Third Assessment Reports of the IPCC (Pearce *et al.*, 1996; Smith *et al.*, 2001).

The numbers apart, Kemfert also makes a methodological point, namely that of adding general equilibrium effects to the direct costs of climate change. Unfortunately, she does not compare the two, and we have not been able to construct this comparison from her paper. The economics effects of climate change "lower[…] other investments". This is a bit disappointing. The great advantage of computable general equilibrium models is that one can look at economy-wide effects of different shocks to different sectors. If the shock to the economy is uniform, and only affects investments, one might as well use a growth model.

Let us use a Solow-Swan model, for instance, with a Cobb-Douglas production function and constant growth rates of population and technology (see Romer, 1996). The equations of motion of this economy are:

(1) $$K(t+1) = (1-d)K(t) + s\,A(t)\,K(t)^{a}\,L(t)^{1-a}\,(1-D(t))$$

(2) $$A(t+1) = (1+g_A A(t)); L(t+1) = (1+g_L L(t))$$

where K is capital, A is total factor productivity, and L is labour; $ä$=0.1, $ó$=0.2, $á$=0.2, g_A=1.01 and g_L=1.01 are parameters; t is time measured in years; and D is the climate change impact. In the first scenario, we set D=0 and the other variables initially to their relative steady state values. In the second scenario, we let D grow linearly from 0.005 to 0.018, as suggested by Kemfert's Table 11. Figure 2 displays the direct impact of climate change as well as the induced reduction in GDP. Figure 2 qualitatively resembles Figure 1; the direct costs (Table

11) were just copied; the reduction of GDP starts at zero and rises, more or less linearly, to just above the direct costs in 50 years time.

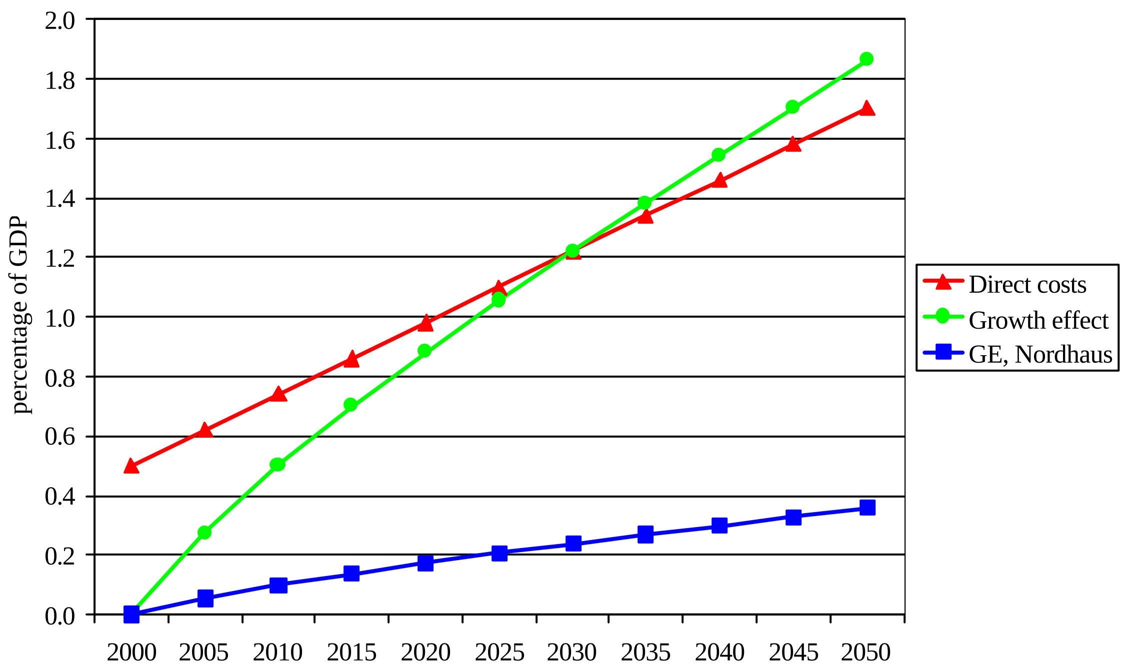

Figure 2. The direct costs and the indirect costs (growth effect only) of climate change, using a Solow-Swan model with inputs after Kemfert's Table 11; two estimates of the growth effect are shown, one after Kemfert ("growth effect") and one after Nordhaus ("GE, Nordhaus").

Results in all CGE models critically depend on the model structure. Unfortunately, Kemfert does not fully explain all key characteristics and assumptions of the WIAGEM model. However, some choices seem fairly standard, whereas others are not. In the following, let us consider a few non-conventional model characteristics, and their implications in terms of realism and reliability of the simulation findings.

First, the modelling of international trade is very *ad hoc*. Although any national economy includes 11 industries, all non-energy sectors enter into a single composite macro good. Furthermore, the macro-good is split, in a CET function, between domestic and exported products. Only the exported macro-composite is traded internationally. Does this matter for climate change impacts? Yes! An important feature of climate shocks is the differentiated impact among industries and regions: some sectors are more vulnerable than others; some sectors are more integrated than others in the national and international economic structure. This is why one wants to use a CGE model: to explore the systemic effects of changes in relative competitiveness. Unfortunately, these important effects cannot be captured in a model in which a single good is traded internationally. This composite good includes everything: from non-tradable personal services to quasi-homogeneous materials.

Second, Kemfert is largely silent on the process of investment and capital formation. However, one model characteristic seems clear: there is one world interest rate, and only one capital market, equalizing capital yields in the alternative investment destinations. This is a grossly unrealistic assumption. Capital returns vary widely around the world; investment portfolios exhibit a very significant "home bias"; domestic savings and investments are highly correlated, despite the apparent integration of international capital markets. Neglecting this feature would imply a large overestimation of economic growth in developing countries, unless one uses *ad hoc* capital controls. Does this matter for estimating climate change impacts? Yes! Vulnerability to climate change depends, *inter alia*, on poverty and development, which in turn depend on national and international investment. Furthermore, the estimated growth effect of climate change is driven by the formulation of the process of capital formation.

In WIAGEM, optimal savings are endogenously determined using a Ramsey formulation. However, the initial calibration is to observed savings. Do these match? Kemfert (p. 288) claims that "the intertemporal optimal dynamic allocation is characterized by a steady state growth path". Is the model in steady state also at the initial time step? Is there a transition phase from the initial state to the optimal path? Presumably, the steady state with climate change (policy) differs from the steady state without. What are the transition dynamics from one steady state to the other? Without fully understanding the model dynamics, it is hard to assess the model results. These issues may explain the occasionally irregular results in Kemfert's Table 11.

Third, on the consumption side, Kemfert models the utility function of the representative consumers as a sort of CES production function. The CES is a homothetic function: the income elasticity for all consumption goods is unity. (Other CGE models use, instead, more sophisticated functions, allowing for differentiated income elasticities.) Does this matter for long-run simulations? Yes! When economies grow, consumption shifts away from energy intensive basic needs to more elaborated goods and services. This has obvious implications for the forecasting of greenhouse gases emissions, but also for the relative competitiveness of each nation, and, particularly, for the relative importance of sectors vulnerable to climate change.

Given these simplifying assumptions used in Kemfert's CGE, it is not altogether surprising that we are able to mimic its behaviour with a Solow-Swan model: the growth engine of WIAGEM is very simple.

Kemfert produces an indirect, growth effect of climate change that is very large. The question is whether this estimate is realistic. In Kemfert's formulation, climate change melts away investment. That is, if the impact of climate change is equivalent to 1% of GDP, investment falls by 5% (using a savings' rate of 20% as above). In Nordhaus' (1994) DICE model, climate change melts away production, so that a 1% reduction in GDP reduces investment only by 1%. Figure 2 also shows the growth effect using this formulation. It is, as expected, considerably smaller. (See Fankhauser and Tol, 2001, for a more extensive discussion.)

However, the growth effect even as estimated by Nordhaus' method may be too large. For, the direct impacts include many intangibles. The "ecological impact", for instance, is the income loss equivalent, in welfare terms, to a loss in biodiversity. The ecological impact is not an income loss, and it does not directly affect output or investment. A similar argument holds for health impacts.

As to the general equilibrium effects of climate change, Kemfert unfortunately does not estimate these. This is not a trivial exercise, anyway. Typically, climate change impact studies report results either in physical units (e.g., change in total yield) or in welfare equivalents (e.g., percent GDP). A CGE outputs welfare estimates, so welfare losses are useless as an input. Similarly, a CGE outputs changes in total agricultural production, and cannot use estimates of such changes as inputs. In order to include climate change impacts in a CGE, the outputs of impact studies need to (painstakingly) reworked into variables that can be used in a CGE. Such variables include changes in endowments (e.g., for land lost to sea level rise), changes in productivity (e.g., for agriculture), changes in demand (e.g., for energy), changes in government expenditures (e.g., for coastal protection), and changes in the (expected) return on investment (as a result of the above changes). To date, nobody has succeeded in doing this in an internally consistent manner for a comprehensive set of climate change impacts.

Acknowledgements

We had useful discussions about the topics of this paper with Francesco Bosello, Carlo Carraro, Sam Fankhauser, Claudia Kemfert, Hans Kremers, Marco Lazzarin and Kerstin Ronneberger. The Volkswagen Foundation through the ECOBICE project, the US National Science Foundation through the Center for Integrated Study of the Human Dimensions of Global Change (SBR-9521914) and the Michael Otto Foundation provided welcome financial support.

References

Darwin, R.F. and Tol, R.S.J. (2001), 'Estimates of the Economic Effects of Sea Level Rise', *Environmental and Resource Economics* **19**, 113-129.

Darwin, R.F., Tsigas, M., Lewandrowski, J. and Raneses, A. (1995), *World Agriculture and Climate Change - Economic Adaptations,* Agricultural Economic Report **703**, U.S. Department of Agriculture, Washington, D.C.

Deke, O., Hooss, K.G., Kasten, C., Klepper, G. and Springer, K. (2001), *Economic Impact of Climate Change: Simulations with a Regionalised Climate-Economy Model*, Kiel Working Paper **1065**, Institute of World Economics, Kiel.

Fankhauser, S. and R.S.J. Tol (2001), *On Climate Change and Growth*, Research Unit Sustainability and Global Change **FNU-10**, Centre for Marine and Climate Research, Hamburg University, Hamburg (submitted to *Resource and Energy Economics*).

Kemfert, C. (2002), 'An Integrated Assessment Model of Economy-Energy-Climate – The Model Wiagem', *Integrated Assessment*, **3** (4), 281-298.

Nordhaus, W.D. (1994), *Managing the Global Commons: The Economics of Climate Change*, The MIT Press, Cambridge.

Pearce, D.W., Cline, W.R., Achanta, A.N., Fankhauser, S., Pachauri, R.K., Tol, R.S.J. and Vellinga, P. (1996), 'The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control', In Bruce, J.P., Lee, H. and Haites, E.F., (Eds.) (eds.) *Climate Change 1995: Economic and Social Dimensions -- Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 179-224. Cambridge University Press, Cambridge.

Romer, D. (1996), *Advanced Macroeconomics*, McGraw-Hill, New York.

Scheraga, J.D., Leary, N.A., Goettle, R.J., Jorgenson, D.W. and Wilcoxen, P.J. (1993), 'Macroeconomic Modeling and the Assessment of Climate Change Impacts', In Kaya, Y., Nakicenovic, N., Nordhaus, W.D. and Toth, F.L., (Eds.) (eds.) *Costs, Impacts and Benefits of CO_2 Mitigation*, International Institute for Applied Systems Analysis, Laxenburg.

Smith, J.B., Schellnhuber, H.-J., Mirza, M.Q., et al (2001), 'Vulnerability to Climate Change and Reasons for Concern: A Synthesis', In McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S., (Eds.) (eds.) *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, pp. 913-967. Press Syndicate of the University of Cambridge, Cambridge, UK.

Tol, R.S.J. (2002a), 'New Estimates of the Damage Costs of Climate Change, Part I: Benchmark Estimates', *Environmental and Resource Economics*, **21** (1), 47-73.

Tol, R.S.J. (2002b), 'New Estimates of the Damage Costs of Climate Change, Part II: Dynamic Estimates', *Environmental and Resource Economics*, **21** (1), 135-160.

Working Papers

Research Unit Sustainability and Global Change

Centre for Marine and Climate Research, Hamburg University, Hamburg

Roson, R. and R.S.J. Tol (2003), *An Integrated Assessment Model of Economy-Energy-Climate – The Model Wiagem: A Comment*, **FNU-26**

Yetkiner, I.H. (2003), *Is There An Indispensable Role For Government During Recovery From An Earthquake? A Theoretical Elaboration*, **FNU-25**

Yetkiner, I.H. (2003), *A Short Note On The Solution Procedure Of Barro And Sala-i-Martin for Restoring Constancy Conditions*, **FNU-24**

Schneider, U.A. and B.A. McCarl (2003), *Measuring Abatement Potentials When Multiple Change is Present: The Case of Greenhouse Gas Mitigation in U.S. Agriculture and Forestry*, **FNU-23** (submitted)

Zhou, Y. and Tol, R.S.J. (2003), *The Implications of Desalination to Water Resources in China - an Economic Perspective*, FNU-22 (submitted)

Yetkiner, I.H., de Vaal, A., and van Zon, A. (2003), *The Cyclical Advancement of Drastic Technologies*, FNU-21

Rehdanz, K. and Maddison, D. (2003) *Climate and Happiness,* **FNU 20** (submitted)

Tol, R.S.J., (2003), *The Marginal Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties,* **FNU-19** (submitted).

Lee, H.C., B.A. McCarl, U.A. Schneider, and C.C. Chen (2003), *Leakage and Comparative Advantage Implications of Agricultural Participation in Greenhouse Gas Emission Mitigation*, **FNU-18** (submitted).

Schneider, U.A. and B.A. McCarl (2003), *Implications of a Carbon Based Energy Tax for U.S. Agriculture*, **FNU-17** (submitted).

Tol, R.S.J. (2002), *Climate, Development, and Malaria: An Application of* FUND, **FNU-16** (submitted).

Hamilton, J.M. (2002), *Climate and the Destination Choice of German Tourists,* **FNU-15** (submitted).

Tol, R.S.J. (2002), *Technology Protocols for Climate Change: An Application of* FUND, **FNU-14** (submitted to *Climate Policy*).

Rehdanz, K (2002), *Hedonic Pricing of Climate Change Impacts to Households in Great Britain*, **FNU-13** (submitted to *Climatic Change*).

Tol, R.S.J. (2002), *Emission Abatement Versus Development As Strategies To Reduce Vulnerability To Climate Change: An Application Of* FUND, **FNU-12** (submitted).

Rehdanz, K. and Tol, R.S.J. (2002), *On National and International Trade in Greenhouse Gas Emission Permits*, **FNU-11** (submitted).

Fankhauser, S. and Tol, R.S.J. (2001), *On Climate Change and Growth*, **FNU-10** (submitted to *Resource and Energy Economics*).

Tol, R.S.J.and Verheyen, R. (2001), *Liability and Compensation for Climate Change Damages – A Legal and Economic Assessment*, **FNU-9** (forthcoming in *Energy Policy*).

Yohe, G. and R.S.J. Tol (2001), *Indicators for Social and Economic Coping Capacity – Moving Toward a Working Definition of Adaptive Capacity*, **FNU-8** (*Global Environmental Change*, **12** (1), 25-40).

Kemfert, C., W. Lise and R.S.J. Tol (2001), *Games of Climate Change with International Trade*, **FNU-7** (submitted to *Environmental and Resource Economics*).

Tol, R.S.J., W. Lise, B. Morel and B.C.C. van der Zwaan (2001), *Technology Development and Diffusion and Incentives to Abate Greenhouse Gas Emissions*, **FNU-6** (submitted).

Kemfert, C. and R.S.J. Tol (2001), *Equity, International Trade and Climate Policy*, **FNU-5** (*International Environmental Agreements*, **2**, 23-48).

Tol, R.S.J., Downing T.E., Fankhauser S., Richels R.G. and Smith J.B. (2001), *Progress in Estimating the Marginal Costs of Greenhouse Gas Emissions*, **FNU-4**. (*Pollution Atmosphérique – Numéro Spécial: Combien Vaut l'Air Propre?*, 155-179).

Tol, R.S.J. (2000), *How Large is the Uncertainty about Climate Change?*, **FNU-3** (*Climatic Change*, **56** (3), 265-289).

Tol, R.S.J., S. Fankhauser, R.G. Richels and J.B. Smith (2000), *How Much Damage Will Climate Change Do? Recent Estimates*, **FNU-2 (***World Economics*, **1** (4), 179-206)

Lise, W. and R.S.J. Tol (2000), *Impact of Climate on Tourism Demand*, **FNU-1** (*Climatic Change*, **55** (4), 429-449).