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Uncertainty in emissions projections in the MIT Integrated Global System Model

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The MIT Integrated Global System Model (IGSM) is a set of coupled sub-models that include the Emissions Prediction and Policy Analysis (EPPA) model as well as those that simulate atmosphere, ocean, and terrestrial earth systems. Emissions scenarios from EPPA are used as inputs into a coupled chemistry/climate model along with natural emissions of greenhouse gases from Natural Emissions Model as they change with climate and other forcings. The IGSM includes an urban air chemistry model for treating emissions in urban areas and the Terrestrial Ecosystems Model simulates carbon and nitrogen dynamics of terrestrial ecosystems. These features allow the IGSM to project concentrations of the relevant trace gases and other pollutants, accounting for photochemical processes and the feedback of climate on natural emission sources; radiative forcing from these trace gases; temperature and precipitation at different latitudes (longitudinally averaged) and global mean; and sea level rise due to thermal expansion of the oceans.

Future emissions of greenhouse gases, their climatic effects, and the resulting environmental and economic consequences are subject to substantial uncertainties. Analysis of possible future climate changes should include quantification of the uncertainty in climate projections. Many climate models use prescribed greenhouse gas emissions scenarios. Ideally, the uncertainties in emissions scenarios are jointly considered with uncertainties in climate models. For many climate models, however, it is not computationally feasible to run hundreds of scenarios. We evaluate the uncertainty in the future anthropogenic emissions using a computable general equilibrium model of the world economy. A significant source of uncertainty in future emissions is a result of uncertainty in future economic growth and technological change. Unlike physical proper-

ties, results of human behavior such as these are not well explained or predicted, and the future will not necessarily be the same as the past. We develop emissions projections that are consistent with underlying economic, demographic, and technological assumptions across substances for any year and over time. For describing and quantifying uncertainties we use the following steps. First, all assumptions of the economic model are subjected to sensitivity analysis. Alternative values for each parameter are tested to see which result in the greatest change in the model outcome. This is used to identify the most influential assumptions for further detailed study. The second step is to construct descriptions of the full range of possible alternatives for each assumption and the relative likelihood of each alternative assumption. The third step is to conduct Monte Carlo simulation, in which we randomly sample from the distributions of model assumptions and calculate the corresponding model outcome. After repeating this process many times, the frequency distribution of outcome values becomes an estimate of the uncertainty in that outcome, conditional on the assumed distributions of inputs. As a result, we develop and present a set of emissions scenarios that describe a central tendency and high and low cases that bound an explicit probability. We use the climate sub-model of the IGSM to compute the climate impacts that result from the scenarios. We present the results simulated through 2100 for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), sulfur dioxide (SO_2), black carbon (BC), organic carbon (OC), nitrogen oxides (NO_x), carbon monoxide (CO), ammonia (NH_3), and non-methane volatile organic compounds (NMVOCs).

This work updates a previous study. New results we report take advantage of recent studies of the historical patterns of economic growth and energy efficiency change that has attempted to sort out the contribution these phenomena have made from the effects of changing energy prices. These studies have sought to use historical data to estimate uncertainty in these major determinants of energy use and GHG emissions, thus reducing the reliance on expert judgment. While human systems and responses in the future are not constrained by past behavior we argue that historical data where available should at least be used to inform expert judgment about future trends.

A critical issue we investigate is the degree of correlation among the growth rates of nation's economies. We find that if the longer run economic prospects of different economies are uncorrelated then future emissions uncertainty is much less than if they are highly correlated; the nature of Monte Carlo sampling means that samples with relatively high economic growth (and thus rapid emissions growth) in some regions likely are offset by slow economic (and emissions) growth in other regions, reducing greatly the likelihood of generating parameter sets where all regions grow either rapidly or slowly. There is potential evidence for correlation among growth rates, but also obvious examples where country specific factors dominate (slow growth of economies of Russia and much of eastern Europe in the 1990's and in Japan, while the US and countries like China and India grew rapidly). Empirical results on correlation have limited statistical significance because adequate data series are too short. Moreover an important economic trend has been increasing interactions among economies as communication, transport and mobility costs have declined with improving technology, thus making the long-term historical record of perhaps limited relevance to the future. Further investigation of the likely degree of correlation among future economic growth rates of countries is one area that could lead us to narrow the range of future emissions forecasts.