Efficiency of climate policy

SIR — There is growing interest among policymakers about the cost of alternative approaches for reducing emissions of carbon dioxide. Particular attention has been paid to the use of energy taxes to limit emissions.

Our analyses[1,2] suggest that the problem of designing an efficient tax system to reduce CO_2 emissions is more complicated than indicated in the literature. Although existing studies have attempted to bound the likely range of taxes necessary to limit CO_2 emissions and the resulting macroeconomic impacts, little consideration has been made of variations in the cost and effectiveness of taxes as they are imposed at different levels of the market. For example, taxes may be imposed at primary production (for example, the well-head or mine mouth), or at the distribution to end-use level (for example, natural gas delivered to homes for space heating; oil deliveries to utilities to produce electricity).

To illustrate the importance of this issue, we used the Environmental Protection Agency's GEMINI model to examine the effectiveness of taxes on carbon and the energy content of fuels, and *ad valorem* taxes, to stabilize CO_2 emissions in the United States at 1990 levels, when they are imposed at different levels of the market. The results indicate that smaller carbon and energy-content taxes are needed to stabilize CO_2 emissions when they are imposed at the primary production level than at the end-use level. In addition, the cost to society (measured as the change in consumers' plus producers' surplus) is smaller when carbon and energy content taxes are imposed at primary production. We found that a \$120 per tonne carbon tax imposed at primary production results in stabilization, whereas a higher \$180 per tonne tax is required at the distribution to end-use level. A \$3.3 per million British thermal units (MMBtu) tax imposed at primary production results in stabilization, whereas a \$4 per MMBtu tax is required at the end-use level. The key reason for these results is the same for both types of taxes: the level of the market at which an energy tax is imposed is important when one form of fossil fuel (such as coal) is converted into another fuel (such as synthetic gas). In our analysis, synthetic gas from coal becomes a substitute for domestic and liquid natural gas imports starting in 2010. Synthetic gas used at the end-use level has a much lower carbon content than the coal from which it is converted. Thus, the surcharge due to a carbon tax is lower when the tax is applied to the synthetic gas than when it is applied to the coal at primary production. (Similar reasoning applies to the Btu tax.)

In contrast, an *ad valorem* tax has the biggest impact on CO_2 emissions when imposed at the distribution to end-use level. A 125% tax imposed at end-use achieves stabilization, whereas no tax less than 200% imposed at primary production stabilizes emissions. Also, the cost to society is smaller when the tax is imposed at the end-use level. This result also arises due to a synthetic fuels effect.

Comparing the results for the three types of taxes examined in this analysis reveals that CO_2 emissions are stabilized at the lowest social cost when a carbon tax is imposed at the level of primary production. These results, taken together, suggest that unless policymakers consider the level of the market, misleading conclusions could be drawn about the potential cost and effectiveness of climate-change policy.

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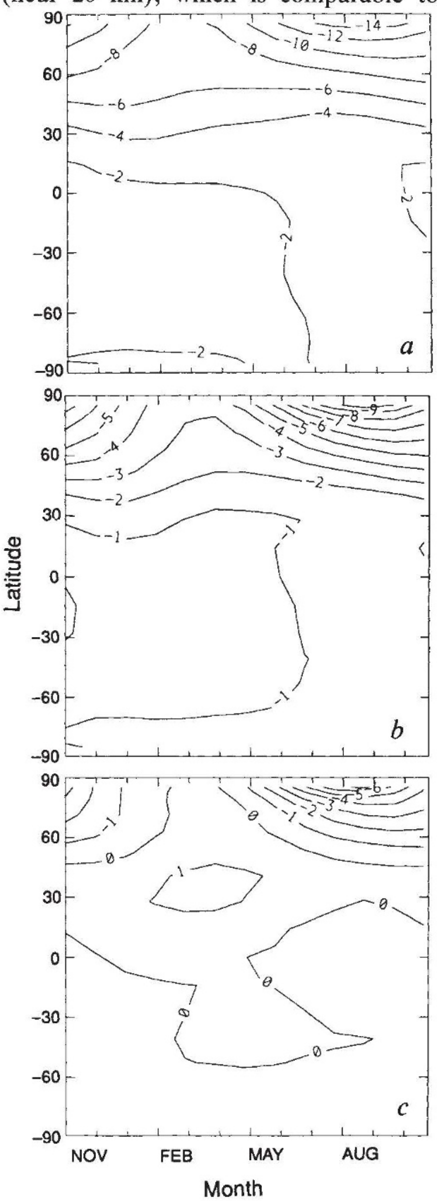
Future aircraft and global ozone

SIR — The impact of the proposed development of commercial fleets of high-speed civil transport aircraft flying in the stratosphere has been studied by Johnston *et al.*[1], who calculated significant global ozone reductions due to NO_x (NO and NO_2) emission, but considered only homogeneous gas-phase chemistry. However, the region of injection coincides with the stratospheric aerosol layer, consisting of droplets of sulphuric acid solution. Heterogeneous reactions on this layer are now thought to affect the global ozone balance[2], particularly following volcanic eruptions, which considerably increase the available surface area[3,4]. The heterogeneous reaction

$$N_2O_{5\,(g)} + H_2O_{\,(l)}\ \text{(sulphate aerosol)} \rightarrow 2\,HNO_{3\,(g)} \qquad (1)$$

is likely to affect the impact of NO_x emissions by the proposed aircraft, as N_2O_5 is a key reservoir for NO_x in the absence of sunlight.

We have used a radiative-chemical-transport two-dimensional model[5] to calculate changes of ozone due to NO_x aircraft emission with and without reaction (1). The reaction probability $\gamma = 0.06$ (ref. 6) and the aerosol surface area is varied latitudinally by translating the observed vertical profile of the background surface area[3] parallel to the tropopause. The typical heterogeneous stratospheric removal time of N_2O_5 is thus calculated to be 6 days (near 20 km), which is comparable to



Calculated column ozone decrease (%) as a function of month for the year 2020 and an injection of 15×10^{10} kg yr^{-1} (ref. 1) for 5 years (2015–2020) at 19.25 km. NO_x emission index, 15 g (NO_2) per kg (fuel). *a*, Gas-phase chemistry only; *b*, including reaction (1) with the background surface area and γ=0.06; and *c*, with doubled background surface area and γ=0.14. Calculations are relative to the background atmosphere for the year 2020: Cl_x, 4.8 p.p.b.v.; N_2O, 327 p.p.b.v.; CH_4, 2.4 p.p.m.v.; CO_2, 418 p.p.m.v. We assume a latitudinal distribution of fuel usage: 19° N (9.79%), 28° N (15.64%), 38° N (27.83%), 47° N (33.00%) and at 57° N (13.74%).