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Submission to the Stern Commission on the Economics of Climate Change

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December, 2005

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0 Introduction

I am an Associate Professor of Economics at the University of Guelph in Ontario, Canada. I hold a Ph.D. in Economics from the University of British Columbia and I have been studying climate change and environmental economics for the past 10 years. I have published peer-reviewed articles in numerous economics journals such as *Journal of Environmental Economics and Management*, *Environmental and Resource Economics*, *The Canadian Journal of Economics* and *The Journal of Regulatory Economics*. My economics research has covered computable general equilibrium modeling of carbon taxes, asymmetric information in policy-setting problems, efficiency concepts in regulatory design and time series analysis of the connection between economic growth and environmental quality. I have also completed an analysis[1] (with Mark Strazicich) of the stationarity properties and probability distributions of the Intergovernmental Panel on Climate Change (IPCC) greenhouse gas scenarios.

In recent years I have worked also on some issues in the physical sciences, publishing peer-reviewed papers in *Climate Research*, *Geophysical Research Letters* and *Energy and Environment*. My work has focused on empirical analysis of temperature data, including examinations of nonclimatic biases in surface temperature series[2] and, somewhat famously, a critique of the 'hockey stick' graph of the IPCC. That project, coauthored with Stephen McIntyre, led to a Corrigendum by the original authors in *Nature*, and a series of controversial publications[3] that have been discussed in news items in *Science*, *Nature* and the *Economist*, among others.

My 2002 book *Taken By Storm: The Troubled Science, Policy and Politics of Global Warming*, coauthored with Christopher Essex, was runner up for the Donner Prize for best book on Canadian Public Policy and a finalist for the Canadian Science Writers' Association Book of the Year.

In recent years I have begun to synthesize some of what I have learned about the process by which climate science connects with the policymaking process. I am concerned about the lack of recognition of the limitations of journal peer-review as a guarantor of reproducibility of empirical results, and about the propensity for scientific assessment panels to acquire systematic biases in the report-generating process.[4]

In this submission I wish to focus on some theoretical topics directly related to the issue of setting socially-efficient targets for greenhouse gas emission reductions. In particular I want to discuss some

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[1] McKitrick and Strazicich (2005).
[2] McKitrick and Michaels (2004).
[3] McIntyre and McKitrick (2005a—d, 2003).
[4] A very insightful treatment of the problems of bias formation in group deliberation processes is in DeMarzo et al. (2003). My own work is in McKitrick (2005a,b).

technical aspects arising from applications of the theory of optimal taxation to the question of the efficient control of externalities. The major conclusions of my submission can be summarized as follows.

- Controls on CO_2 emissions will generate unusually large scarcity rents. The question of how these rents are distributed has a decisive impact on the overall cost of the emissions control policy as well as on the question of whether any emission reductions can be economically justified.
- Empirical work in the USA has shown that ambitious CO_2 reduction policies cost more than the social benefits they generate, especially if they do not involve complete rent capture. If the most efficient policies are adopted, it is still only possible to justify very small CO_2 emission reductions.

1 Some Comments on the Scientific Background

Carbon dioxide has not traditionally been regulated as an air contaminant, because it is a harmless, naturally-occurring part of the atmosphere, just like oxygen and water vapour. Attention is now being paid to it because of its possible connection to long-term climate trends. I am, myself, unconvinced that the popular picture of CO_2 being a major driver of climate change is well-established. The underlying issues in radiation and atmospheric fluid dynamics are, in part, governed by the well-known Navier-Stokes equations, which are not solvable into a form that permits direct computation of the phenomena of interest. This forces scientists to model the problem using indirect parameterizations and empirical approximations. Climate models, like macroeconomic models, are useful for many purposes, but not for long-term prediction or for attributing causation to finely-partitioned aspects of the chaotic system governing our weather and climate. Since the "signal detection" studies used by the IPCC use climate model-generated data for their analysis they provide inherently weak forms of evidence. Contemporary thermometer records exhibit upward trends in many places, but my and others' examination of the data has shown that the spatial pattern of land-based trends is well-explained by the spatial pattern of economic activity and the ensuing impacts on land use and local atmospheric conditions. The IPCC has never adequately addressed these conspicuous nonclimatic correlations in the climatic data base. My reading of the data and literature has lead me to conclude that the underlying "climatic" changes are smaller than is suggested by the simple straight-line trends examined by the IPCC.

The size of present-day trends in temperature data, even if they are *prima facie* valid, does not support a conclusion of unnatural change unless they appear to be out of the range of natural paleoclimatic variability. The IPCC has been very determined to promote evidence that natural climatic variability is quite small, a bias that led them to adopt the hockey stick graph as an icon in their 2001 Report. Stephen McIntyre's and my work seems to have been the first independent effort to verify that graph. We showed that it is fatally undermined by an undisclosed variant in the principal component method which not only biases its final shape but also falsely exaggerated its statistical significance.

In venturing into topics in the physical sciences I am struck by the insularity and defensiveness of the IPCC. I am now an expert reviewer for the Fourth Assessment Report and I was dismayed by the failure of the draft authors to acknowledge or deal constructively with most of the substantive criticisms of the IPCC position that have been published in scientific journals since 2001. While I do not intend to take up these larger themes in the rest of this submission, I note that a sound policy agenda cannot be based on a biased and incomplete picture of the scientific background. There are structural problems preventing the communication of a balanced, complete and accurate picture of the state of climate science into the policymaking process. Any attention that this Inquiry can give to these larger issues would be a valid and much-needed service to the public.

2 Post-1970 CO_2 Emissions

Some empirical background will help frame the discussion. UK CO_2 emissions from 1970 to 2002 are shown in Figure 1. A reduction from ~175 Megatonnes (MtC) to ~150 Megatonnes occurred prior to 1985, well before modern greenhouse gas emissions control policy. Subsequently, emissions have been relatively constant except for a spike at 1990. During the interval 1970 to 2000 the UK economy grew nearly 89% in real terms, and from 1985 to 2000 it grew nearly 44% in real terms, according to the Penn World Tables.[5] Consequently Figure 1 implies an impressive improvement in the emissions intensity of the UK economy since 1970, with an apparently permanent reduction of the absolute level of emissions having occurred in the 1970-1980 interval.

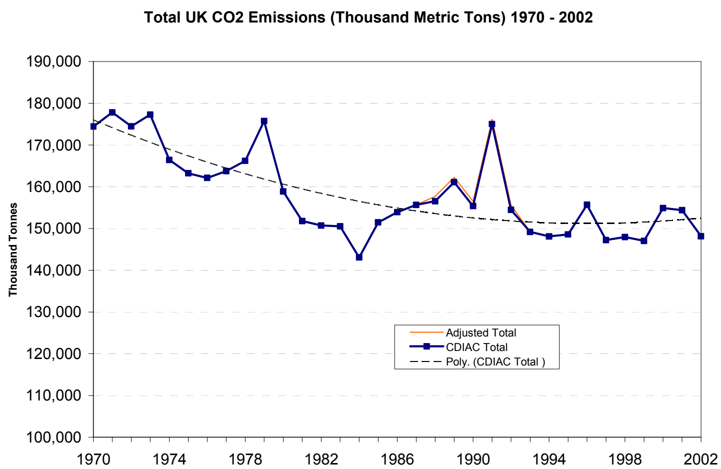

Figure 1. UK CO_2 Emissions 1970 to 2002. Blue line: CDIAC Total (Carbon Dioxide Information and Analysis Center, http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm). Orange line: 1988-1992 Gas flaring estimates missing for UK so these were assumed to equal 1,150 Kilotonnes each year, yielding the small adjustment as shown. Dashed line: 2nd degree polynomial trend through CDIAC total.

For Western Europe as a whole[6] the picture is somewhat different. Figure 2 shows that there is no downward trend over time. Emissions peaked at ~700 MtC in 1979 then again at ~670 MtC in 1991.

[5] Series RGDPL ADJUSTED FOR TERMS OF TRADE CHANGES.
[6] See country list at http://cdiac.esd.ornl.gov/trends/emis/weulist.htm.

Thereafter emissions fell temporarily but have begun to climb steadily since 1994 and as of 2002 had nearly reached the 1979 peak.

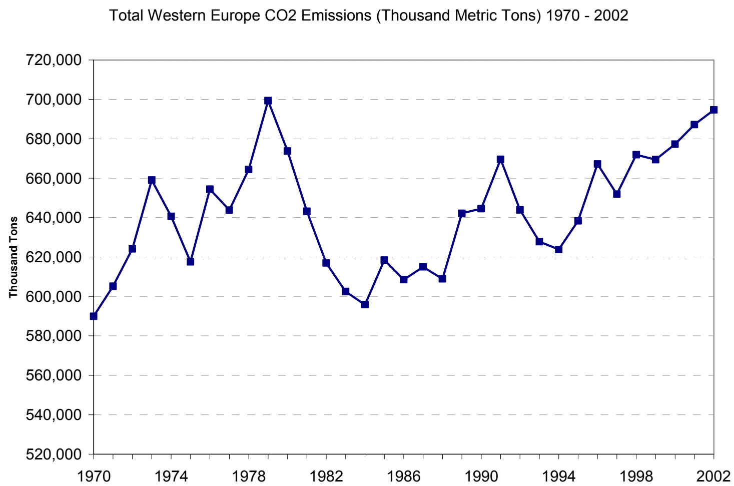

Figure 2. Western Europe CO_2 Emissions 1970 to 2002. CDIAC Total (Carbon Dioxide Information and Analysis Center, http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm)

3 Pollution Control via Prices or Quantities

People and firms generate air pollution emissions because the emitting activities are valuable to them. It is common in economic models to treat emissions as a "factor of production." While the emissions themselves are not productive, the right not to spend money on otherwise unproductive abatement allows a firm to earn a higher rate of return. Hence, for each emission level, there is a marginal benefit to a firm of being allowed to increase emissions slightly. The marginal benefit can equally be interpreted as a marginal abatement cost: the cost to the firm of being required to reduce emissions slightly. Hence the marginal abatement cost, or MAC, line is a common graph in environmental economics textbooks. It is intuitively identical to the "demand curve" for emissions, relating a quantity of emissions to a price, where the price is the marginal benefit of additional emissions or the marginal cost of additional abatement. Figure 3 illustrates an MAC line. Unregulated emissions are at $\bar{e}$ where the marginal benefits are zero.

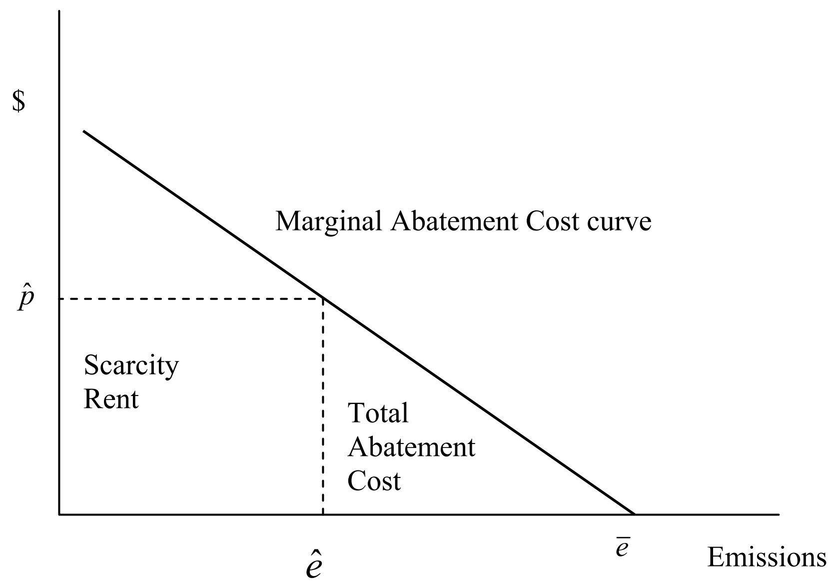

Figure 3. The "Demand" for Emissions = Marginal Abatement Cost Curve (MAC)

As with any demand curve, a policy setting a quantity must leave the price undetermined, and vice-versa. If emissions control is accomplished by a quantity standard at $\hat{e}$ then the shadow price $\hat{p}$ is the associated MAC. Or, if emissions control is accomplished by a charge of $\hat{p}$ on emissions then the resulting quantity of emissions is $\hat{e}$.

3.1 Total Abatement Costs, Variable Costs and Scarcity Rents

In Figure 3, the cost to a firm of reducing emissions from $\overline{e}$ to $\hat{e}$ is the triangular area under the MAC, indicated as the Total Abatement Cost. These are, by definition, the variable costs. Many conventional air contaminants, such as carbon monoxide and sulphur dioxide, have been dramatically reduced since the early 1970s. The success is partly due to the fact that these contaminants were controllable by technologies involving a manageable fixed cost, and relatively small variable costs. An example is the introduction of catalytic converters on automobiles, which require a single up-front addition to the cost of the car, but no appreciable increase in the operating costs. For such pollutants the MAC line has a shallow slope and the Total Abatement Costs are relatively small, leaving aside the cost of the fixed abatement capital.

Carbon dioxide is not controllable by conventional air pollution treatment options involving mainly fixed, or sunk costs, such as smokestack scrubbers and automobile catalytic converters. Instead, changes in the composition of fuels and reductions in overall fuel consumption are needed. Hence the cost of CO_2 abatement differs from conventional air pollution because it involves relatively high variable costs and thus a relatively steep MAC.

The rectangular area defined by the dimensions $\hat{p} \times \hat{e}$ represents scarcity rents created by the controls on emissions. These rents are created regardless of whether the policy captures them for the regulator or leaves them in the hands of the emitting firm. They are not new wealth, they are simply rents created by the artificial scarcity arising from the legal limits placed on emitting activity.

If the policy consists of a tax on emissions, the tax revenue is $\hat{p} \times \hat{e}$, hence the rents are captured by the government. If the policy consists of an emission standard at $\hat{e}$, the rents $\hat{p} \times \hat{e}$ are effectively given to the firm, or 'grandfathered'. If the policy is a tradable permits system, the rents may be captured by the government if the permits are auctioned off (in which case the policy is formally equivalent to a tax), or it may be grandfathered to the firms by a free endowment of permits, or some combination of the two. In the US Sulfur Dioxide market, of the ~9 million permits available each year (one for each ton of allowable emissions) all but 150,000 are grandfathered to existing firms, and the rest are auctioned by the government.

3.2 Cost-Effective Policy

Figure 3 illustrates, schematically, the situation for a single firm facing a regulation on emissions. When *n* firms are regulated the resulting total emissions *E* is the sum of individual firms' emissions. For a given total emissions target, denoted $\hat{E}$, the optimal distribution of emission targets among firms is determined by the "equimarginal" rule $MAC_i = MAC_j$, which simply states that MAC's should be equal between any two firms *i* and *j*. If MAC's are not equal, it would be possible to reallocate allowable emissions from a low MAC-firm to a high-MAC firm, reducing overall abatement costs while keeping emissions constant.

Policies which achieve cost-effectiveness, i.e. equal MAC's across all sources, are called "economic instruments." They include emission taxes and tradable permits. Policies like standards and indirect subsidies (e.g. for wind power, etc.) do not typically attain cost-effectiveness and hence are not "economic instruments." Nor can they be described as "cost effective". The same overall emissions control could, in principle, be achieved at lower cost.

When policies equate marginal abatement costs across firms, the individual MAC's can be summed horizontally to an industry- or economy-wide MAC (just as individual demand curves can be summed horizontally to yield a market demand curve). The same division between Total Abatement Costs and Scarcity Rents can be sketched out for an aggregate MAC, and the result looks like Figure 3. In the absence of an equimarginal outcome, the policy still creates scarcity rents and causes total abatement costs to be incurred, but they may be much larger and not so easily visualized or measured.

The aggregate MAC is equivalent to an industry demand curve for emissions. In the case of a tradable permits system, the demand curve for permits reveals the aggregate MAC. As with any dynamic market, the MAC, or emissions demand curve, should not be assumed to be static over time. In the US sulfur dioxide market the initial interaction between demand and supply for permits yielded a market price of about $100 per ton through much of the 1990s, implying scarcity rents of $900 million/year. However, while the permits supply is still just under 9 million, the permit price has now climbed to over $1200 per ton, implying scarcity rents of nearly $11 billion/year. These almost all accrue to the owners of emitting firms, under the permit allocation formula.

Figure 1 suggests that the "demand" for CO_2 emissions in the UK is likewise not static. In the 1970—1985 interval, emissions were unregulated but the demand curve moved leftwards so that the unregulated level fell from about 175 MtC to about 150 MtC. Since then the demand curve has continued to shift right and left, implying unregulated emission levels in the 140 – 160 MtC range, though in the more recent years some policies have been in place to limit emissions, so the observed level may no longer be the unregulated level.

3.3 Efficient Policy

To maximize the welfare gain of reducing emissions, the standard prescription is to reduce total emissions to the point where MAC equals the marginal social damages of emissions. This is the optimal emissions level, denoted in Figure 4 as E^*. Under an emissions tax policy this can be done by setting a uniform charge on emissions equal to the marginal damages (MD) of emissions evaluated in the neighbourhood of the optimum E^*. In the case of CO_2, since even large quantities of emissions have very small effects on atmospheric concentrations it is customary to draw the MD line as horizontal.

In Figure 4 I have drawn the MD line as positive, though estimates of damages due to carbon dioxide are not necessarily above zero for the world as a whole (Mendelsohn et al. 2000) or for individual countries. For Canada, several independent studies have predicted net economic gains in agriculture and forestry (Weber and Hauer 2003, Reinsborough 2003). Some studies propose global MD amounts in the range of US$5 – $20 per ton, but since so little modern economic activity is affected by the outdoor climate it would be difficult to find credible estimates running above this.

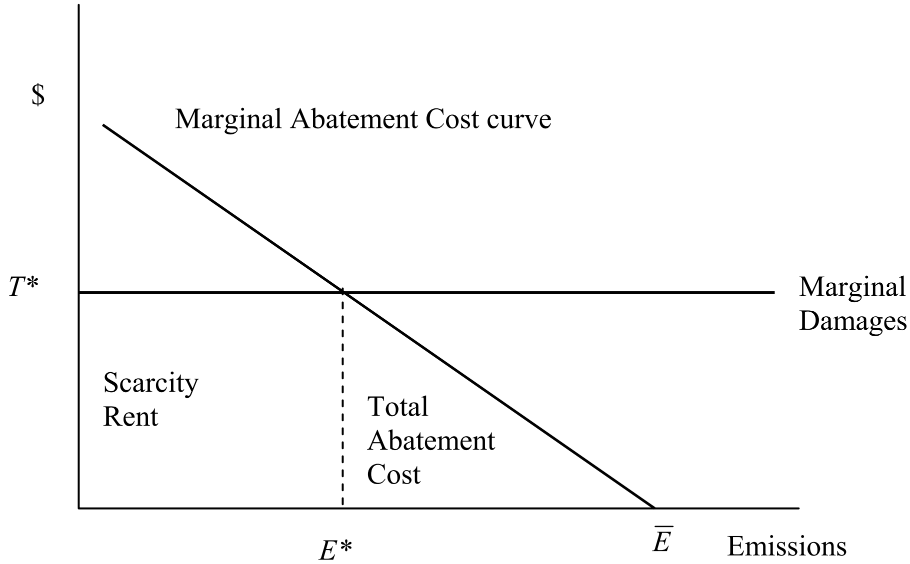

Figure 4. The Optimal Emissions Level where Marginal Abatement Costs (MAC) = Marginal Damages (MD).

4 Tax Interactions and Revenue Recycling

The prescription implied by Figure 4 is an emissions charge equal to marginal damages, say at US$10 per ton of carbon. However this rule only applies in a hypothetical, idealized economy with no prior tax distortions. When the effects of a distorting tax system are taken into account the analysis changes in such a way as to reduce the optimal shadow price of emissions.

If an emissions tax is used, the tax revenue might be recycled into reductions in other income taxes. Suppose the UK were to implement a carbon dioxide tax at a rate of £100/tonne, achieving a 10% reduction in emissions from 150 MtC to 135 MtC, with annual total abatement costs of £750 million.[7] This seems a small amount, but it would be accompanied by annual scarcity rents of £13.5 billion. They could, in principle, be applied to reducing income taxes, generating a welfare gain to offset the total abatement costs. This is known as the "revenue recycling effect."

However the imposition of the carbon tax also creates an interaction effect with the existing tax system. The emissions control policy increases the cost of consumption, which reduces the real wage rate. Since

[7] The Total Abatement Cost triangle has area (in millions) of 0.5x(150-135)x100 if the MAC is linear.

the opportunity cost of leisure falls, the labour supply curve shifts up and a higher nominal wage must be offered to induce the same supply as before. On its own (i.e. if the labour tax rate remained unchanged) the government's real tax revenue from the labour market would be lower. This "tax interaction effect" implies that, to maintain government revenue neutrality it is not possible to apply all of $\hat{p} \times \hat{e}$ to reducing the labour tax rate (e.g. Parry 1995). If the policy does not even capture the rents in the first place, other taxes must be raised to maintain revenue-neutrality, thereby increasing the social costs of the policy.

Hence the disposition of rents created by the emissions control policy matters. The tax interaction effects are created regardless of whether the rents are captured or not. But if the rents are not captured the revenue recycling benefits are not achieved.

Key to the distinction in this analysis is the presence of pre-existing distortions in the economy attributable to the excess burden of the rest of the tax system. If there were no taxes (or only lump-sum taxes) then the revenue-recycling and tax interaction effects would be zero. But in a distorted tax system both effects increase in size as the general burden of the tax system rises. In actual economies, the tax interaction effects are likely to be larger than the revenue-recycling benefit (Parry 1995, Bovenberg and Goulder 1996).

Without revenue recycling the policy is even more costly. Suppose the policy is a set of grandfathered emission standards, as is the case in the US sulphur dioxide market. Then the amount $\hat{p} \times \hat{e}$ accrues to the permit holders and the government does not raise as much additional revenue as it would if the permits were auctioned (the only additional revenue raised by the government is income taxation of the scarcity rents).

Parry, Williams and Goulder (1999) used analytical and numerical models to show that, in the case of US carbon dioxide emissions, if the pre-existing tax rate on labour is 40%, the tax interaction effect was so strong relative to the revenue recycling effect that under grandfathered tradable quotas, the first unit of carbon emissions reduction would have an overall economic cost of at least $18 (US) per ton, or $66 per ton of CO_2.[8] If quota rents are not themselves subject to taxation the marginal cost of the first unit of emissions reduction would be over $29 per ton of carbon. But if emissions are taxed and the revenues are used to reduce labour taxes the marginal cost of emission reductions begin at zero. For a 20% reduction in emissions, an emissions tax would have a marginal cost of just over $60 per ton whereas tradable quotas would have a marginal economic cost of over $100 per ton.

Translating to the UK context, I conjecture that the marginal cost of emission reductions are even higher than in the US (though it is a matter that needs to be settled by consulting the relevant empirical studies. The income and consumption tax load is higher in the UK than in the US, moreover the reduction in emissions prior to 1985 suggests that the UK has already exploited the lowest-cost CO_2 control options. In the US, by contrast, the heavy reliance on coal and the relatively low fossil energy taxes suggest there are more low-cost abatement options available. Consequently, carbon emission policies in the UK that do not fully capture and recycle scarcity rents can be assumed to generate marginal economic costs starting at least at US$66 per ton of CO_2.

[8] The factor of conversion from carbon to CO_2 is 11/3.

These results suggest that, even if marginal damages of CO_2 emissions were, say, \$10 per ton, any amount of emissions reduction would be welfare-reducing under a tradable quota scheme. This seems counterintuitive, since in Figure 4 the diagram shows the MAC reaching zero at $\bar{e}$, and if marginal damages are positive it is clearly optimal to reduce emissions, *ceteris paribus*. The point of the tax interaction literature is that the distortions in the economy due to the tax system create a hidden category of *policy costs*. If these are taken into account the standard MAC curve should be re-drawn as shown in Figure 5. If the marginal damages are *MD* and we only consult the *MAC* curve, the diagram would imply emissions should be reduced from E_1 to E_2. But if a policy is introduced which fails to capture all the scarcity rents for recycling we need to refer instead to *MAC+policy costs*, which as drawn implies that no emission reductions can be economically justified.

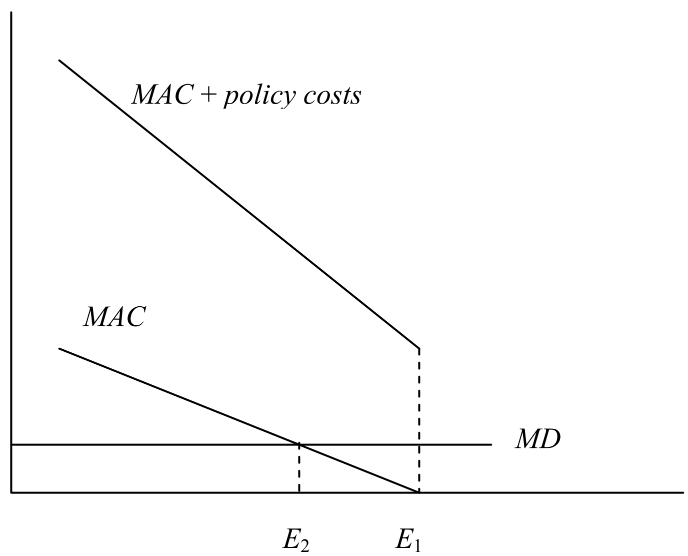

Figure 5. Optimal emissions control taking policy costs into account

5 Second-Best Taxation with Externalities

If rents are captured but the tax system is still distorting, the analysis in Figure 5 can be modified to show that the optimal emissions tax rate ought to be less than marginal damages. This has been known ever since the elegant work of Agnar Sandmo in the *Swedish Journal of Economics* in 1975, who extended the Diamond-Mirrlees optimal tax framework to include an externality-generating commodity.

The Sandmo model uses *n* identical consumers facing *m*+1 commodities, where good 0 is leisure and good *m* generates a disutility such that total consumption of good *m* enters each utility function as a negative effect. Production is via a Leontief model. If the public sector needs to use commodity and factor taxes to meet its revenue requirement the optimal tax system is given by two types of taxes:

$$\theta_k = (1-\mu)\left[R_k\right] \qquad (5.1)$$

for k=1,…,m-1; and

$$\theta_m = (1-\mu)\left[R_m\right] + \mu\left[MD\right] \qquad (5.2).$$

The term R_k in (4.1) is a 'Ramsey'-type expression indicating the optimal level of the revenue-raising tax component. If all cross-price derivatives are set equal to zero it reduces to the inverse of the own-price elasticity, confirming the elementary textbook result that taxes should be relatively higher on goods with inelastic demand. In (4.2) the term in the second pair of brackets is the Samuelsonian-type expression for marginal damages in the context of the Sandmo model, namely the summation of the marginal rate of substitution between good *m* and the associated externality. The parameter μ will be explained below.

Equation (4.2) tells us that the externality component of the tax is additive, and moreover that it only enters the formula for the *m*-th good, not for any of the others. For instance, even if good *m* is complementary with some other good *k*, the externality associated with *m* does not justify an environmental tax on *k*. If good *m* is, for instance, gasoline, then policy should be directed at gasoline, not at complementary goods like cars; nor should policy take the form of subsidies for substitutes (e.g. ethanol or wind energy). If there are social costs associated with gasoline, then put the tax on gasoline.

In Sandmo's model the parameter μ is the ratio of the marginal utility of private and public income (formally, the Lagrange multipliers from the household and public sector optimizations). It indicates the amount of income the public would have to earn to offset the welfare loss of a dollar to the private sector while leaving overall welfare constant. In an economy with no tax distortions, the value of a dollar lost to the private sector exactly equals the value of the dollar gained by the public sector. In this case we would have μ=1. The only non-lump sum tax would be the one on good *m*, and it would be equal to marginal social damages. But in the presence of distorting taxes, the value of a dollar given up to taxation exceeds the (social) value of the additional public income, because of the deadweight loss. Hence μ<1 when there are tax distortions in the economy, and the optimal environmental tax should be smaller than it otherwise would be.

The parameter μ is related to the concept of the marginal cost of public funds (MCPF) and it is approximately the case that $\mu = 1/MCPF$. If the marginal excess burden of the tax system is 40%, the Sandmo model implies an optimal emissions tax should be set at $MD/1.4 \cong 0.7 \times MD$. Parry (1995) derives similar conclusions in a much simplified partial equilibrium model.

This is a counter-intuitive point: in very distorting tax systems we should not raise pollution taxes, other things being equal we should lower them. The intuition is that as the level of distortions in the tax system rise, all public goods—including environmental protection—get more costly and subject to lower levels of optimal provision.

This analysis is only concerned with policies which fully capture scarcity rents and which do so using cost-effective economic instruments. If emissions policy fails to capture the scarcity rents, no CO_2 emission reductions are likely justifiable in the UK, as was discussed in the previous section. If scarcity rents are captured, and if the marginal damages of carbon are US$10 per ton, a tax of ~$7 per ton could be justified. Empirical analyses for Canada and the US indicate that this would yield very small emission reductions (a few %), certainly too little to achieve Kyoto-style targets, much less more ambitious targets like a 60% reduction; nor would a tax at this level stop emissions from growing as the economy grows. Most of the policy ideas that have received attention in the UK in recent years would not receive support in a quantitative welfare analysis, such as

- Subsidies for non-fossil energy sources;
- Ambitious emission reduction policies with targets of 25—60%;
- International permits trading with grandfathering of the initial allocations.

6 Conclusions

I have presented some general concepts arising from environmental economics to help frame the Inquiry's thinking about CO_2 emission control policy options for the UK. The main conclusions are:

- There is an important distinction between policies that achieve cost-effectiveness and those that do not. Reliance on policies that do not achieve cost-effectiveness only guarantees that any emission reductions are achieved at higher costs than are necessary.
- There is also an important distinction between policies that capture scarcity rents and those that do not. *All* emission control policies create scarcity rents. These rents are transferred from existing beneficiaries of the emitting activity (including consumers) to those who, under the policy, implicitly or explicitly hold the right to the emitting activity. Because of the large volume of national CO_2 emissions and the potentially high marginal cost of abatement, these rents are non-trivial in magnitude.
- Greenhouse gas policies that fail to capture the scarcity rents have been shown in US analysis to have discrete policy costs even at very low levels of emissions control. It is unlikely that any level of emissions reduction can be economically justified if the policies explicitly or implicitly grandfather the emission rights.
- A carbon tax that fully appropriates the scarcity rents for revenue recycling purpose still generates negative tax interaction effects. Even in a second-best optimal tax system the appropriate emissions price should be below the estimate of marginal damages, by a factor approximately equal to the inverse of the marginal cost of public funds. In the case of carbon dioxide, this puts an upper limit on the optimal price well below that which would yield deep emission cuts of the kind called for under Kyoto or other more ambitious proposals.

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APPENDIX: Abstracts to Selected Publications

McIntyre, Steven and Ross McKitrick, (2003). "Corrections to the Mann et. al. (1998) Proxy Data Base and Northern Hemisphere Average Temperature Series." *Environment and Energy* 14(6) pp. 751-771

The data set of proxies of past climate used in Mann, Bradley and Hughes (1998, "MBH98" hereafter) for the estimation of temperatures from 1400 to 1980 contains collation errors, unjustifiable truncation or extrapolation of source data, obsolete data, geographical location errors, incorrect calculation of principal components and other quality control defects. We detail these errors and defects. We then apply MBH98 methodology to the construction of a Northern Hemisphere average temperature index for the 1400-1980 period, using corrected and updated source data. The major finding is that the values in the early 15th century exceed any values in the 20th century. The particular "hockey stick" shape derived in the MBH98 proxy construction – a temperature index that decreases slightly between the early 15th century and early 20th century and then increases dramatically up to 1980 -- is primarily an artefact of poor data handling, obsolete data and incorrect calculation of principal components.

McIntyre, Stephen and Ross McKitrick (2005c) "The M&M Critique of the MBH98 Northern Hemisphere Climate Index: Update and Implications" *Energy and Environment* 16(1) pp. 69-100.

We show that differences between the results of McIntyre and McKitrick [2003] and Mann et. al. [1998] are attributable to special methods applied in MBH98 that enhanced the effect of a Gaspé cedar ring series and caused the shape of the PC1 from the North American tree ring network to be dominated by a small group of bristlecone pines with dubious status as temperature proxies. The influence of these series cause the final results to be sensitive to minor methodological choices: slight variations yield, alternatively, 15th century values that are greater or lower than 20th century values, refuting claims by Mann et al. that their conclusion of uniquely high 20th century values is "robust". We also show that heavy reliance on bristlecone pine and cedar series as proxies for temperature is unsupported. We then refute the various arguments by Mann et al. purporting to salvage their reconstruction, including their claims of statistical skill. Finally, we consider lessons the MBH98 example provide concerning the need for "full, true and plain disclosure" in scientific contexts, especially where public policy is at stake.

McIntyre, Stephen and Ross McKitrick (2005d) "Hockey Sticks, Principal Components and Spurious Significance" *Geophysical Research Letters*Vol. 32, No. 3, L03710 10.1029/2004GL021750 12 February 2005.

There is considerable interest in "hockey stick"-shaped paleoclimate temperature reconstructions, following the seminal studies of Mann et al. (1998, 1999). However it has not been previously noted in print that they carried out an unusual data transformation prior to their principal component (PC) analysis on tree ring networks, which affects the resulting PCs. We show their method, when applied to persistent but trendless red noise, nearly always produces hockey-stick shaped PC1s and overstates the first eigenvalues, and that these PC1s, regressed against Northern Hemisphere

temperature, establish a benchmark for 95 and 99% RE significance which is not met by the AD1400 step of the MBH98 reconstruction. We show that, in the actual AD1400 reconstruction in MBH98, the algorithm effectively selects only one species (bristlecone pine) into the PC1 making it implausible to describe it as the "dominant" climate signal.

McKitrick, Ross R. (2005a) "Science and Environmental Policy-Making: Bias-Proofing the Assessment Process", *Canadian Journal of Agricultural Economics*, Vol 53, 2005, p. 275—290.

Scientific assessment panels are playing increasingly influential roles in national and international policy formation. While they typically appeal to the standard of journal peer review as their quality control criterion, there seems to be confusion about what peer review actually does. It is, at best, a necessary condition of reliability, but not a sufficient condition. There is also the problem that assessment panels may be biased in favour of one side or another when evaluating areas in which the science is unclear. In this paper I argue that additional checks and balances are needed on the information going into scientific assessment reports when it will be used to justify major policy investments. I propose two new mechanisms to bias-proof the outcome: an Audit Panel and a Counterweight Panel. The need for such mechanisms is discussed with reference to the "hockey stick" debate in climate change.

McKitrick, Ross R. (2005b) McKitrick: "Bringing Balance, Disclosure and Due Diligence into Science-Based Policymaking". In Porter, Jene (ed.) *Public Science in Liberal Democracy: The Challenge to Science and Democracy*, University of Toronto Press, forthcoming.

I look at three settings in which complex, uncertain information must be used to support a decision that will have institutional implications and may thereby impinge on others in society: court trials, business prospectuses and science-based policymaking. In the first two one can identify formally-coded rules that ensure balance, full disclosure and due diligence occurs, thereby putting the decision on the most secure footings possible in terms of truthfulness and fairness. In the policymaking case, there is little evidence that these principles apply in a systematic way, and with respect to the climate change issue they are conspicuously absent. I suggest some mechanisms for reforming the policy process that would bring public sector decision-making up to standards approaching those in the courts and the private sector.

McKitrick, Ross and Mark C. Strazicich (2005). "Stationarity of Global Per Capita Carbon Dioxide Emissions: Implications for Global Warming Scenarios" University of Guelph Department of Economics Discussion Paper 2005-03. (submitted for publication)

Annual global CO_2 emission forecasts at 2100 span 10 to 40 billion tonnes. Modeling work over the past decade has not narrowed this range nor provided much guidance about probabilities. We examine the time-series properties of historical per capita CO_2 emissions and conclude that per capita global emissions are stationary without trend, and have a constant mean of 1.14 tonnes per person with standard deviation of 0.02. With estimates of 21st century peak population levels in the 8-

10 billion range, this implies that most emissions scenarios currently used for global warming forecasts are unrealistically high.

McKitrick, Ross and Patrick J. Michaels (2004). "A Test of Corrections for Extraneous Signals in Gridded Surface Temperature Data." *Climate Research* 26(2) pp. 159-173. See also "Erratum" Vol 27(3) 159—173.

Monthly surface temperature records from 1979 to 2000 were obtained from 218 individual stations in 93 countries and a linear trend coefficient determined for each site. This vector of trends was regressed on measures of local climate, as well as indicators of local economic activity (income, gross domestic product [GDP] growth rates, coal use) and data quality. The spatial pattern of trends is shown to be significantly correlated with non-climatic factors, including economic activity and sociopolitical characteristics of the region. The analysis is then repeated on the corresponding Intergovernmental Panel on Climate Change (IPCC) gridded data, and very similar correlations appear, despite previous attempts to remove non-climatic effects. The socioeconomic effects in the data are shown to add up to a net warming bias, although more precise estimation of its magnitude will require further research.