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**WORKING PARTY ON  
GLOBAL AND STRUCTURAL POLICIES**

**OECD Workshop on the Benefits of Climate Policy:  
Improving Information for Policy Makers**

**What do we know about climate policy costs and  
how can we learn more?**

by

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## FOREWORD

This paper was prepared for an OECD Workshop on the *Benefits of Climate Policy: Improving Information for Policy Makers*, held 12-13 December 2002. The aim of the Workshop and the underlying Project is to outline a conceptual framework to estimate the benefits of climate change policies, and to help organise information on this topic for policy makers. The Workshop covered both adaptation and mitigation policies, and related to different spatial and temporal scales for decision-making. However, particular emphasis was placed on understanding global benefits at different levels of mitigation -- in other words, on the incremental benefit of going from one level of climate change to another. Participants were also asked to identify gaps in existing information and to recommend areas for improvement, including topics requiring further policy-related research and testing. The Workshop brought representatives from governments together with researchers from a range of disciplines to address these issues. Further background on the workshop, its agenda and participants, can be found on the internet at: [www.oecd.org/env/cc](http://www.oecd.org/env/cc)

The overall Project is overseen by the OECD Working Party on Global and Structural Policy (Environment Policy Committee). The Secretariat would like to thank the governments of Canada, Germany and the United States for providing extra-budgetary financial support for the work.

This paper is issued as an authored "working paper" -- one of a series emerging from the Project. The ideas expressed in the paper are those of the author alone and do not necessarily represent the views of the OECD or its Member Countries.

As a working paper, this document has received only limited peer review. Some authors will be further refining their papers, either to eventually appear in the peer-reviewed academic literature, or to become part of a forthcoming OECD publication on this Project. The objective of placing these papers on the internet at this stage is to widely disseminate the ideas contained in them, with a view toward facilitating the review process.

Any comments on the paper may be sent directly to the author at:

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## EXECUTIVE SUMMARY

How much a policy is *expected to cost* and who will be bearing the brunt of it play a significant role in the debates that shape regulations. We do not have a good track record of predicting costs, but a systematic review of past assessments has identified the factors that lead to errors. A wide range of expected costs of climate policy have been hotly debated, but *all* are likely to be wrong. This does not mean that we should continue a debate using ill informed analyses. On the contrary, we need early small experiments to shed light on key unknowns. Climate policy is a long-term challenge and an adaptive regulatory approach promises to inform policy targets and improve GHG controls by through sequential regulatory phases that promote: innovation, flexibility and diffusion of best technologies.

## 1. INTRODUCTION

In many issues, national politics determines predisposition to specific policies and their implementation. In the US of 2002 few question the *cost* of anti-terrorism activities. It has become a national priority since 9-11. In contrast, uncertainty about climate change and its impacts led some economists to question whether the cost of climate policy is worthwhile (Nordhaus 1977). In Europe, the resolve to address other structural changes, such as the demise of coal miners in the UK and unification in Germany relegated climate change economics to a secondary issue. These structural changes permitted a shift away from high carbon fuels and Climate policy became an ancillary benefit of these other national priorities. Nonetheless, as we contemplate steps toward and beyond the first Kyoto compliance period *expected* cost and benefit estimates continue to drive climate policy design and timing. But what can these expectations be based on?

Unfortunately, we have no direct experience with policies aimed at reducing greenhouse gas emissions (GHGs). This handicaps the regulators, the regulated and analysts trying to offer insights about policy design. The closest analogues to climate policy have been the energy crises of 1973 and 1979. Neither of these events were deliberate, announced *policies* to manage energy use. They precipitated energy policies in many OECD countries, but analysis of experience with these policies is contaminated by the impact of the political and psychological aspects of the crises and the macro-economic policies enacted concurrently with energy policies. Therefore, this historic experience provides a good basis for analysis of poor energy crisis management, and a poor basis for estimating the costs and efficacy of a well-designed climate policy.

### 1.1 Shortfalls of modelling

As a consequence of this lack of direct experience, today's *ex ante* assessments of the cost of climate policy at the level of firms, households and the economy are almost exclusively based on modelling exercises. These model results may appear to have been sanctified by the CPU, but reflect significant subjective inputs from their developers both in terms of model structure and parameter calibration. Their structure, ranges from: detailed bottom-up models reflecting engineering economic details of a wide menu of technologies in each sector, to top-down models of the whole economy calibrated on historic data about a few to hundreds of sectors.

Bottom-up models are favoured by analysts and policy promoters who assert climate policy will have low or negative costs. They identify numerous technological changes that could be adopted today, saving costs and GHG emissions. They blame lack of information and market imperfections as reasons for the poor diffusion of "clearly superior" technologies. They often believe that information programs and market reforms are all that hampers more rationality and savings for investors.

In my view, when a *model* identifies the world as behaving illogically, one can blame the world or recognize that something must be amiss in the model. Bottom-up models describe how the world *should* be not the way *it is*. These models lack behavioural realism in terms of factors beyond cost and efficiency (e.g., reliable data, ability to process the data into knowledge, access to capital, structural constraints, status, ...) that shape and bound consumer choice and investment.

Top-down models are favoured by analysts and policy promoters who worry that climate policy costs will be high. They are calibrated on economic indicators of the past – almost always spanning the two oil crises. They reflect the response of socio-economic indicators to many technical, social and economic perturbations. They tend to not have information about specific technologies. However, as noted above, the applicability of these response patterns to a new challenge is questionable. For example, the US has never had a deliberate and careful energy policy, so why should micro and macro economic responses to the forced and sudden changes in energy prices and availability expectations in the latter third of the 20<sup>th</sup> century be a guide to the costs and efficacy of such a deliberate policy in the 21<sup>st</sup> century?

Top-down and bottom-up approaches are both of limited value in the study of a long-term issue like climate change. Even the most technically detailed models tend to be too myopic about the dynamics of technology and the most detailed economic models are still bereft of how preferences evolve. For example, I know of no model developed as recently as 1997 that included direct CO<sub>2</sub> capture and sequestration. This is not even a new technology, but well-known set of technologies cobbled together to address a new challenge. The equivalent issue in top-down models is that even the most behaviourally detailed codes do not reflect how a cost can become an investment as a choice about a social goal is turned into an imperative for civil society. This will happen if/when we treat climate stability as a right of other species and societies. For example, one hundred and seventy years ago the Abolitionists faced studies enumerating the cost of freeing slaves in terms of lost productivity and higher prices. Would *anyone* advocate such a calculus today?

Given these known foibles of current assessment methods do we have sufficient information about costs and benefits to provide useful information for climate policy? The continuing debate on costs and benefits would suggest not. The subjectivity of modellers is reflected in the simple observation that for every model stating zero or low costs of compliance there is another that reports them to be astronomic. Postponement of useful knowledge is all that can be gained through this battle of models and perspectives. The solution lies in well-designed policy experiments to reveal cost and efficacy of different approaches to GHG controls. Ideally, these should have started *before* Kyoto, in order to inform realistic goals for the first compliance period of Kyoto. Today, they are needed in order to have an iteratively better informed approach to the subsequent phases of GHG controls.

## 1.2 Lessons from past environmental regulations

In order to design better climate policy experiments we should learn from our experience with past environmental regulations. I plan to draw upon a growing body of literature devoted to evaluation of past regulations in order to understand sources of possible bias in *ex ante* cost estimates of climate policy. Understanding bias in *ex ante* cost estimates is critical to making sure that policy experiments, designed to reveal strategy, costs and efficacy, are not themselves disruptive or misleading.

Experience with past regulations has helped us understand whether and why the *ex ante* and *ex post* costs for a particular regulation have been significantly different. A review of the current literature also reveals two critical gaps in applicability of lessons from past regulations: a) few studies have focussed on the impact of policies on costs borne by households, b) few, if any, past regulations will have impacts so far beyond their immediate target (industry, sector, ...) as climate policy. Both of these shortcomings will mean that we need to be particularly vigilant about the adverse effects of policy in these areas.

Ideally, climate policy should: stimulate innovation, impose costs that are easily absorbed by households, industry and government, deliver GHG reductions, not have unexpected and distant adverse effects and as a bonus advance other environmental and social goals beyond climate change.<sup>1</sup> Climate

<sup>1</sup> Note that as long as other social and environmental issues dominate climate change as a source of public concern, they should be the primary target of our efforts with GHG controls as the ancillary benefit.

policy will be a century long iterative process, with mitigation and adaptation targets evolving as we learn more about how to manage economic activity and global environmental perturbations. An important aspect of this long-term engagement will be to treat it as a learning process where policy at any stage provides information on how to take the next step. What we have done over the past decade – prevarication through duelling models and endless procrastination will simply deny us the opportunity of designing smart and well-informed policies.

In section two a definition of costs is offered along with identification of factors (boundary and baseline) critical to any cost analysis. The validity and accuracy of boundary and baseline of cost studies are all too often taken for granted. The third section is devoted to a review of the literature exploring differences between *ex ante* and *ex post* costs of regulations. The fourth section addresses the challenges in developing realistic assessment of policy impacts for industry. Section five addresses impact assessments at the household level. Section six steps proposes an adaptive management framework to address the unknowns and develop smarter sequential policies.

## 2. TWO CHALLENGES IN COST ESTIMATION

At the firm level, there are three aspects to costing environmental regulations:

Compliance costs: is the sum of installation, operation and maintenance costs of the pollution control equipment.

Change in production costs: is the overall change in producing a product with and without compliance with the environmental regulations. If the control strategy influences the production process, the change in production costs can be lower or higher than the compliance cost.

Change in baseline: reflects the possibility that changes in production costs (and other factors) impact demand and hence the baseline of uncontrolled emissions is unlikely to match the realized demand once controls are in place.

Firm level costs are critical to their decision-making and shape their responses to proposed regulations. However, in trying to evaluate the welfare impact of public policy we need to move the “boundary of where the costs are measured out to the whole economy. Thus, two key dimensions to cost estimation are the boundary at which impacts of policy are measured and the baseline. The boundary defines how far away from the point of compliance costs are measured. The baseline defines what the counterfactual would have been in the absence of policy. Determination of both present significant challenges conceptually and empirically.

### 2.1 Boundary

If a firm is asked to control some pollutant, the simplest measure of its control costs are capital investments plus operation and maintenance costs incurred in compliance with the regulation. This is the, all else held constant, control cost. However, if in controlling the pollutant the firm is able to recycle a reagent. The overall costs to the firm for a unit of production with control will be lower than anticipated because of the savings in reagent costs. Finally, control costs, changed production processes and consumer preferences may change demand. Any change in demand may change the baseline of required controls and hence lead to overall compliance costs being different to expectations, even when control costs per unit of product have been accurately predicted.

Beyond the factory gate, we run into the question of how the higher cost of a product (now associated with less pollution) are reflected in the economy as a whole. Depending on the relevance of this product to provision of other goods and services in the economy and availability of substitutes, changes in its costs will be attenuated or amplified into costs for the whole economy. Within a bounded national economy it has been shown that, on average, firm level costs of compliance for environmental controls are between 30 and 50% lower than economy-wide impacts (Hazilla and Kopp 1990; Jorgenson and Wilcoxon 1990).

In climate policy we need to consider firm level compliance costs vs. firm level total costs vs. costs for a national economy. Climate policy will vary by nation, influencing terms of trade as well as the decision on where to locate production facilities. Traditional models rarely, if ever, capture the full

subtleties of the broad range of possible responses and their impacts on cost and pathways to compliance. We will return to this issue later in section 4.

Within firms, conventional wisdom had asserted that reported costs of compliance with environmental regulations understate changes in total production costs. Heretically, Porter *et al.* (1995) asserted that compliance could lead to net savings in production costs. Actual empirical evidence points to a different set of conclusions. Morgenstern *et al.* (1998) examined reported and actual compliance costs and changes in production costs at the 4-digit SIC level. They found that, on average, the compliance costs and changes in production costs were not significantly different. They found that on average \$1 in pollution control costs, leads to a change in production costs of ¢81. They found that the relationship of compliance costs and change in production costs varies by industry group. In some industry groups compliance costs are much higher than changes in production costs while in others is it much lower. Among industries with large compliance costs, plastics are notable in having saved ¢80 in production costs for every dollar of control costs (net cost of regulation was therefore 20% of reported). On the other end of the spectrum, production costs at steel mills increased by ¢41 for every dollar of pollution control investments (net costs of regulation was 141% of reported).

There can be many reasons for the range of outcomes across different industries. However, I believe the key lies in whether pollution control afforded opportunities in economies of scope. In other words, compliance with the regulations is not simply an end of pipe treatment of effluents but involves revisions to the production process in fundamental ways. Clearly, in the case of steel, the industry needed costly changes their production processes in order to implement the environmental controls, while in the case of plastics, the control challenge presented an opportunity to manufacture with greater efficiency and cost savings. Such opportunities will vary by industry and rate of technical change. If the arrival of the regulation and a process innovation coincide, large economies of scope can result. If they are out of step, compliance costs and net production costs will both be high.

## 2.2 Baseline

Beyond the issue of where to draw the boundary of cost estimation for a regulation, cost estimation requires comparison of trajectories with and without that intervention. Before a policy is enacted, we project a *baseline* of emissions. Controls are designed to alter this baseline trajectory to a new more acceptable level of emissions. When policies are applied, the counter-factual baseline (e.g., CO<sub>2</sub> emissions without policy) is lost. The difference in the projected baseline and the realized emissions is needed to estimate the impact and cost of policy. This baseline is not simply that of emissions, but also input prices, production costs, market share, profits etc. All of this information is needed in order to arrive at an accurate estimate of the *cost* of a policy.

While acknowledging parameter uncertainties is now common in modelling, structural uncertainties in models are less frequently explored. Structural uncertainties are how we model the way the world works. For example, we can model technical change as: a) an autonomous random process, b) a process governed by rate of investment, c) a process that responds to policy, d) a process that responds to changes in relative factor prices, e) all the above. Each of these models of technical change would yield distinctly different results. A model of autonomous technical change would not have technical change respond to climate policy, R&D investments, or the shadow price of GHG gases. In two studies estimating the cost and efficacy of climate policy the author has shown how structural uncertainties are critical to cost estimation (Dowlatabadi, Hahn et al. 1993; Dowlatabadi 1998). Comprehensive reviews of how technological change is incorporated in climate policy assessments can be found in Azar and Dowlatabadi (Azar and Dowlatabadi 1999) and Weyant and Olavson (Weyant and Olavson 1999).

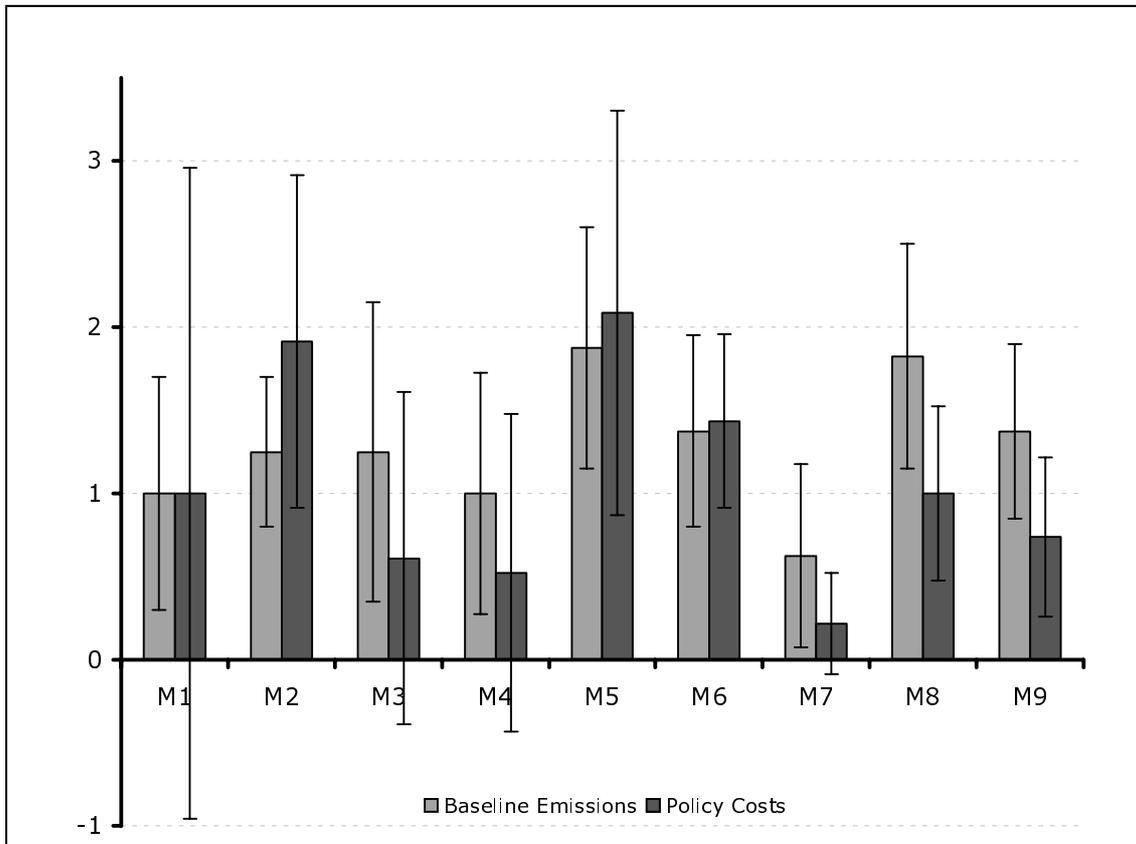
Figure 1 is based on the findings in Dowlatabadi (1998) and displays how different structural assumptions influence the baseline of emissions and the costs of emissions controls. It is very important to note that once different structural assumptions are allowed the same labour inputs and raw productivity assumptions lead to different baselines of emissions. Furthermore, a higher baseline of emissions does not lead to higher control costs.

In Figure 1 several different assumptions about the structure of the energy market were calibrated using the same historic data. For example, in model M1 the rate of technical progress is neither affected by policy nor prices. To a policy maker this is an absurd simplification of the world, but in analysis this is the way most top-down models represent technical change. In M1 the fossil energy industry cannot develop inexpensive new fossil fuel resources. To an expert from the fossil fuels industry this flies in the face of more than a century of new resource discoveries and technological progress reducing the cost of production. Nevertheless, this is how most models represent fossil fuel production. In M1 there is no economics of learning and the first PV cell costs the same as the one millionth unit. This again is demonstrably wrong, but often the mathematical structure of models used in analysis make it very difficult (if not impossible) to include such phenomena. The results generated by M1 are consistent with and typical of the majority of models used in climate policy cost assessment in the 1990s.

In contrast, M9 has technical progress responding to changes in energy prices; the fossil fuel industry are clever in findings new resources and respond to prices too; manufacturers learn from experience with renewable technologies; and, governments implement policies that accelerate the diffusion of technological progress beyond the boundary of nations who have implemented climate control policies – *viz.* JI and CDM. The two different model structures not only change the baseline emissions and costs of control, they also influence whether the uncertainties in these estimates cascade or cancel. The key insight is that the cost of GHG controls is strongly determined by how responsive the energy system is “modelled to be” when stimulated through various policies.

Unfortunately, we do not know which, if any, of these nine model structures is a better reflection of the way the world works. I personally have a favourite (M9) but would not be able to offer solid justification for why it is superior to another model, e.g., M5. Much of our modelling embodies such subjective bias, but we rarely project the implications of such bias in terms of impacts on policy assessment. Furthermore, the indeterminacy of historic evidence and their successful fit to perhaps any number of imaginative models with plausible structures leads to a proliferation of possibilities rather than more assured cost estimates. The only hope is to gather further information reducing address key uncertainties about household, firm and economy level responses to specifics of policy. We shall return to this point in section 6.

Figure 1. Normalized emissions baselines and policy cost estimates using ICAM-3.



Notes: The figure represents results for 9 model structures (M1 to M9). Each model represented a different structural assumption about the machinations of energy markets. These structural assumptions spanned issues from fossil fuel availability and pricing to technical change, learning curves, and responsiveness to policy and prices. Each model's parameters were estimated using the Bayes Monte Carlo procedure. Then each model was run 400 times (using its own structure-specific parameter estimates) to generate the error bars (representing  $\pm 1$  sigma uncertainty) in emissions and policy cost projections. Finally, all emission estimates were normalized to the mean emissions estimated for Model 1 (M1) and all cost estimates were normalized to the mean cost estimated for the same model.

### 3. LESSONS FROM COMPARISON OF *EX ANTE* AND *EX POST* COSTS ESTIMATES

No discussion of policy costs can be divorced from the politics of how and why cost estimates are generated and used. It would be naïve to assume proponents and opponents of a regulation would generate objective cost estimates. It is likely that a proponent would like to overstate baselines and understate costs, while opponents would understate the baseline and overstate compliance and economy-wide costs.

We are not only plagued by many uncertainties (some of which are illustrated in section 2), but these uncertainties are easily dominated by subjectivity. This was illustrated for the case of climate policy evaluation (Lave and Dowlatabadi 1993) and documented in opinion polls<sup>2</sup>. Perhaps governments can be considered relatively “honest brokers” when their goal is to serve public interest. However, government cost estimates have been characterized as systematically too high by advocates of policy and systematically too low by those complaining about the yoke of regulation.

Fortunately, over the past decade the US government has begun Regulatory Impact Assessments (RIA), collecting data that can be used to assess the validity of such criticism.<sup>3</sup> In a pioneering paper made possible by the RIA initiative, Harrington *et al.* (2000) reviewed the direct costs of 28 environmental regulations. A summary of their findings is:

- That in 32% of cases baseline emissions was overestimated, vs. 14% of cases where emissions were underestimated.
- That in 50% of cases unit costs of reduction was overestimated vs. 21% under-estimated unit costs.
- That accuracy of *ex ante* estimates of baseline emissions, unit costs and total costs improved through time.
- That where incentive based regulations were employed, baseline emissions were predominantly under-estimated and unit costs over-estimated. Overall, the total costs of incentive-based regulations were lower than anticipated in 50% of cases, accurate in 25% and indeterminate in the other 25%.

I would like to focus on the implications of the last two findings for the case of cost estimates in climate policy. It is encouraging to learn that we are getting better at estimating the cost of environmental regulations, but the continued wide range of cost estimates in the case of climate change is disheartening. In addition, incentive based regulations appear to have allowed regulatory objectives to be met at lower

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<sup>2</sup> Jon Krosnick found that the balance of public opinion before and after the Clinton White House briefings on climate change did not change, but the public were quicker to respond to questions probing their opinions about desirability of climate protection policies [personal communications 1998].

<sup>3</sup> In September of 1993 US Executive Order 12866 mandated Regulatory Impact Assessment (RIA) for regulations costing over \$100 millions annually. This has provided an opportunity to systematically review different regulations and try to understand factors that may have biased *ex ante* cost estimates of proposed policies.

than expected costs. But the promise of an incentive-based climate policy has been insufficient to allay concerns about the upper end of the cost projections for climate policy. Is this because policy opponents believe the GHG controls present a special case where *ex ante* cost are highly under-estimated and unlikely to be offset through incentive-based regulations?

Theoretically an incentive based scheme introduces flexibility in how the goals of a policy are met. This flexibility can be in: time, space and method of meeting regulatory objectives. It explicitly allows for unknown innovations being employed to reduce baselines and or implement controls. It facilitates the financing and deployment of such innovations through mechanisms such as markets for emission permits. Is there any reason to be wary of the potential for this mechanism to reduce costs of GHG controls as it has done in other realms? The difference between the ideal of a theoretical incentive-based regulation and the messy reality of their implementation can be significant (McCann 1996). I turn to a closer examination of the most celebrated and successful of these regulations in search of further insights.

The most noted example of an incentive based environmental regulation with over-estimated *ex ante* costs is the 1990 US Clean Air Act Amendments (CAA) for control of SO<sub>2</sub>. Many have commented on the *ex ante* cost estimates per unit emission reduction being almost an order of magnitude too high. The literature has been reviewed to better understand more precisely where and why the *ex ante* estimates were biased (Burtraw 1996; Burtraw 1998; Ellerman and Montero 1998).

Six factors can be demonstrated to have led to high *ex ante* cost estimates:

- I. The baseline for Phase I of the regulation was too high. Phase I of the regulation targeted specific power plants with very high emissions rates. The baseline emissions from these power plants were over-estimated. This is attributable to a movement of energy intensive industrial activities away from regions targeted by the regulation. There is little reason to believe that this migration was related to promulgation of the CAA.<sup>4</sup>
- II. There was an incorrect assumption of fuel type inflexibility for existing power plants. Namely, units burning high-sulphur bituminous coals were thought to be incapable of operating on low-sulphur sub-bituminous coals or blends of these fuels.
- III. There were incorrect assumptions about competing fuel prices. The price of all fossil fuels used to generate electricity – in particular gas and oil – were lower in the 90s than when the *ex ante* assessments were made. This has permitted fuel switching and expansion of generation away from coal.
- IV. There was an incorrect assumption about cost of delivering low-sulphur coals from the western mines US to mid-western and eastern power plants. The Staggers Act deregulating railways and investments in new tracks led to falling delivery costs for Powder River Basin coals and significantly greater market share than had been thought possible.
- V. SO<sub>2</sub>-scrubber technology costs fell, while their reliability and performance improved. This occurred even when the capacity of new installations during Phase I was only 30% of *ex ante* projections.
- VI. Emission permits provided time flexibility eliminating the need to invest in spare scrubber units.

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<sup>4</sup> For example, the rise market share of Korean steel and car industries was driven by aggressive industrial and export policies, not the US Clean Air Act. Similarly, falling GHG emissions in Russia is not a consequence of their plan to take a dominant position in international GHG permit markets.

The first 4 factors show that baseline emissions were in error. These errors led to over-estimation of baseline emissions, and unit costs of control. It is inappropriate to attribute these cost “savings” to the incentive-based regulatory design employed in 1990. It is also questionable to attribute the falling cost and improved performance of scrubbers to the regulatory design. By 1990, the technology was reaping the benefits of massive R&D investments in Clean Coal Technology, significant technical advances by German and Japanese manufacturers, as well as the need for flue gas desulphurization to grow competitive with low-cost, low-sulphur coal. Finally, if the time interval over which emissions are measured and/or permits offer a flexible approach to scrubber unit outage, there is no need for spare units.

In addition to the above misattribution of virtue to incentive based schemes, there are three further factors that have increased the *apparent* gap between *ex ante* and *ex post* costs of the CAA. Their impact on a balanced comparison of *ex ante* and *ex post* costs should not be ignored:

- VII. Many comparisons have jumped the gun comparing *ex ante* cost estimates for the complete implementation of the act with results from Phase I of the program. In Phase I only half the ultimate control of SO<sub>2</sub> was sought. Marginal control costs can be expected to rise as tighter emission controls are imposed in Phase II.
- VIII. *Ex ante* cost estimates did not reflect the fine structure of the regulation as implemented.
- IX. The permit prices (used as the proxy for *ex post* cost of compliance) probably understate actual compliance costs. The market for permits has been remarkably thin (Burtraw 1996). This is due to significant heterogeneity (and ambiguity) in treatment of permit economics across different states where local public utility commissions regulate the industry. Thus permit prices in the market are devalued to reflect the uncertainty in their economic value to utilities in other jurisdictions.

An interesting contrast to the often-quoted story of lower than expected SO<sub>2</sub> controls is the relative obscurity of NO<sub>x</sub> control costs. *Ex ante* NO<sub>x</sub> control costs were relatively accurate. With the exception of the first year of implementation, when many hoped to buy excess allowances generated by investing in scrubbers. When the time came, few excess allowances were available and their prices reached many multiples of the *ex ante* estimate. Costs have subsided since then, reflecting controls based on a standard set of technologies.

Before moving beyond the energy sector, it is instructive to contrast the SO<sub>2</sub> controls experience, with the situation for CO<sub>2</sub> controls. Let us first consider the baseline:

- We may be fortunate in that the baseline of economic activity and emissions projected out into the distant future has been overestimated under the influence of a temporary period of exuberance economic growth. This reduces the level of controls needed to achieve any given target, but these less demanding reductions will have to be undertaken under more stringent economic conditions, potentially causing greater loss of welfare as a consequence.
- Unfortunately there is no readily available lower carbon content and cheaper fuel to switch to (as with western low-sulphur coal). Advanced biomass and other renewables hold some promise. However, we have not yet solved how to absorb the inherent volatility in availability and price of biomass fuels. Other renewables continue to pose a challenge in energy storage. Finally, the environmental impacts of switching to renewables/biomass cannot be ignored.
- Fortunately, as with SO<sub>2</sub> controls, there is an end-of-pipe technology to fall back on. CO<sub>2</sub> capture and sequestration (CCS) holds promise as a relatively inexpensive control measure for emissions from large point sources. This alone will reduce the marginal cost of stringent controls by an

order of magnitude. However, control costs of \$25-60/t-CO<sub>2</sub> (Keith 2002) are far from insignificant. But there is hope that costs would fall with experience and that industrial processes based on a CO<sub>2</sub> platform would help make the economics more attractive especially where there is water scarcity (Taylor, Carbonell et al. 2000).

#### 4. FROM IDEALIZED MODELS TO MESSY REALITY: TRADE AND LEAKAGE

The majority of the discussion above has focussed on the energy industry. Climate policy will influence factor inputs to many other industries and has been resisted by those who fear significant negative impacts. In a democratic decision-making environment, distributional features of costs often dominate debates about their absolute levels. Thus, there is a critical need to pay close attention to factors that would lead to anomalous distributional characteristics. But beyond the issue of the cost of compliance, there is a need to also consider the ability of policy to achieve its objective.

Many authors have commented on the issue of leakage in response to climate policy. Leakage works through production being transferred out of a country in response to environmental regulations. The local impact of the regulation is demonstrable reduction in emissions. However, global emissions are only reduced if the new production process and delivery to markets are more efficient in GHG emissions per unit of service delivered.

Models incorporating traded goods where different regulations are in place have demonstrated the significance of leakage in numerous studies (Felder and Rutherford 1993; McKibbin and Wilcoxon 1996; Böhringer and Rutherford 2002). There are political factors shaping details of policies that economists know to be inefficient. These details are rarely modelled and they can bias *ex ante* estimations of policy costs and effectiveness.

Let us take the example of Canada. Not only is she the most open economy in the OECD, her economy is captive of the US market with 87% of exports going there (Statistics Canada 2002). Canada is wrestling with the challenge of designing and implementing policies for meeting her emissions target under Kyoto. Meanwhile the US Federal government has chosen not to pursue GHG control targets negotiated under Kyoto. Industry in Canada lobbied hard against Kyoto, citing loss of competitiveness as their greatest concern. Their concerns did not stop Kyoto, but the policy that has emerged is shaped to ameliorate impacts on industry. The government plans to distribute 85% of the GHG allowances *gratis*. In addition, the government has earmarked numerous financial incentives to promote R&D and investment credits to industry greasing the skids towards greater GHG efficiency and competitiveness in foreign markets.

The government's own study of impacts of these concessions and reaching Kyoto targets suggests economic costs by sector ranging from a high of 3% in the construction industry to a 0.5% gain in energy intensive and trade sensitive sectors. This is typical of analyses designed to reflect how government policies can be tailored to cushion the blow of climate policy to industry (Canadian Government, 2002, page 66). However, not only is there no discussion of the opportunity costs of government revenues being diverted to climate policy, there is little realism in how such policies might impact location decisions by firms and terms of trade with the US.

US firms are aggressive competitors. They are also well aware: a) that they can use the Canadian climate policy (i.e., government support for R&D and capital renewal in manufacturing) as a pretext for the charge of subsidized production costs under WTO rules; b) that in response to this charge the US would impose countervailing duties on Canadian imports placing these at a significant competitive disadvantage; c) that the legal procedures for addressing the charge of manufacturing subsidies would take at least two

years to complete. Meanwhile, the “offending” industry, whether rightly or wrongly accused, could lose its export market and risk extinction before the WTO hearings have been completed.

This depiction of economic competitions being won and lost in a hard-nosed game of legal maneuvers governing “free trade” is not fantasy. For example, in 2001, the US argued that Canadian stumpage fees are too low thereby making Canadian processed lumber exports unfairly subsidized. This was used to unilaterally assess a 29% countervailing duty on Canadian lumber exports to the US. These duties were then passed on to US lumber producers, “to compensate them for unfare losses.” The WTO hearings on this issue are in their second year with no resolution in sight. Meanwhile 40,000 forestry and lumber jobs have been permanently lost in Canada. US firms flush with cash have bought competitors in Canada. And firms with both US and Canadian ownership have invested in new sawmill operations in the US. The hypocrisy of this tragedy is that while all this upheaval is going on in the sawmill industry, the US’s own sawmill operators continue to import round-wood (the wood before it is sawn into lumber) harvested from the same *supposedly* subsidised forests. There is no countervailing duty on these imports! These round-wood imports are creating substantial employment opportunities in lumber mills across the US, and the value added in the sawmill operations are accruing to the US economy.

In the European Union, the open economy is largely echoed in relatively harmonized regulations and environmental targets. In the rest of the OECD the openness of economy is not echoed in environmental and social unanimity. The real-politics of trade are often more evident during periods of economic strife. *If* climate policy dampens growth at a time of economic uncertainty or strife the *ex ante* costs of policy on export-based industries is likely to be severely under-estimated. Consider again, the example of the US-Canada market. Firms with US and Canadian facilities will be given *free* 85% of their GHG emissions limit in Canada as tradable permits, what is to stop them selling these permits and moving production to the US? Their bottom line would be improved; net Canadian emissions would be lowered; but Canada would lose permit revenues and value added from domestic manufacturing. The exchange rate, market price of permits in Canada, and establishment level capital equipment renewal cycles will determine how readily such relocation decisions are implemented.

In conclusion, while some have argued that depending on how Kyoto is implemented, it could have a small impact on costs we can see that the very policies used to reduce compliance costs of firms can lead to firms being motivated to sell grandfathered permits and relocate production elsewhere (Barker and Johnstone 1998; Barker and Srivastava 2001), or generate retaliatory import protectionism where industrial profiles are similar and regulations differ. These aspects of markets are rarely, if ever, considered in estimating the impacts of policy.

## 5. COSTS OF POLICY TO HOUSEHOLDS

Much of the foregoing discussion has focussed on estimating the cost of policies at the firm and economy levels. By and large, these are far better studied/modelled than household response to policies. Nonetheless, in the typical OECD economy, direct household expenditures on energy account for about 1/3 of GHG emissions, while indirectly household expenditures on goods and services generate the lion's share of the rest of the emissions. This alone highlights the importance of household behaviour in response to policy (Schipper, Bartlett et al. 1989; Weber and Perrels 2000).

While I will not be delving into the literature of lifestyles and marketing to develop this theme along its natural course, I will use a particular observation about households to bolster the case for a new approach to regulation (that will impinge on industry and households). I will use household data to illustrate the phenomenon of highly differentiated capacity to respond to information and market signals. I beg the readers indulgence in allow me to take these observations of household decision-making and assert the presence of their equivalent in firm level decision-making.

Presumed *high personal discount rates* have long been used (Jaccard, Loulou et al. in press) to represent more realistically the observation that decision-makers do not respond to cost saving opportunities when returns to such informed decisions *should* be sufficient. While this is a convenient modelling trick, I have been interested in learning how far different decision-makers stray from *economically rational* behaviour. This is of significance when trying to implement market-based regulations with the aim of meeting environmental goals and maximizing welfare.

In analysis of the Residential Energy Consumption Survey (EIA 2001) I stumbled across data that sheds light on two key questions:

- Did actors receive information about energy saving technologies and still not exercise a choice that would reduce overall household energy service costs?
- Did economic rationality have any relationship to economic pressure?

I analyzed data on energy expenditures from a representative sample of US households. 5900 US household records (US DOE Residential Energy Consumption Survey, 1997) were analyzed to shed light on the questions above. The key findings from this analysis are:

- I. 76% of households report being aware of energy savings information and labels on household appliances. Yet, more than 64% of US households do not use guides to energy savings when purchasing energy using appliances
- II. In the 95% of households who pay their own energy bills. Energy efficiency information guides the appliance choices of 37% of households.
- III. In the 5% of households who receive public assistance with their energy expenditures. In only 22% use energy efficiency guides in appliance purchases.

- IV. That 16.5% of US households have residential energy costs exceeding 10% of their declared annual income; 3% of households (3.3 million) have residential energy costs in excess of 30% of their declared incomes.

Why do less than half of those who are informed about energy savings alternatives choose to use that knowledge? Why does facing full market forces only raise the proportion of those who use information to save energy expenditures from 22% to 37%? Why are expenditures of 10% of household income on residential energy insufficient market pressure to promote energy saving investments?

These observations have persuaded me that perhaps the assumption that households have the *freedom to choose* mischaracterises the opportunities facing a significant fraction (at least in the US). More detailed examination of data reveals that if energy expenditures are too low a fraction of household income, there is little response to efficiency information. Furthermore, when energy expenditures are a considerable fraction of household incomes, there may be interest in acting to save energy, but no freedom (perhaps due to agency or capital constraints) to respond to these. This lack of responsiveness is not captured in current models. If market based regulations are employed under the heterogeneity of response noted above, the regulations will cause undue hardship and be ineffective.

These findings, albeit at the household level, question the assumption that *sufficient* market pressure and *adequate* access to information will lead to adoption of *more efficient* technologies. To the best of my knowledge, there is no equivalent dataset from which one could simultaneously establish the degree of awareness about energy saving alternatives and importance of energy expenditures at the firm level. However, the failure of firms to adopt energy-saving technologies with very short payback periods is well documented. I will assume that these failures at the household and firm levels have similar causes and pose equivalent challenges in developing effective regulations.

## 6. A STRATEGY FOR REGULATION WHEN WE DON'T KNOW COSTS

Whenever there is significant uncertainty about costs of a policy there is endless *duels of perspectives* with nary an addition to the factual basis supporting dichotomous assertions. My own experience suggests that proponents and opponents of regulation wage battles bereft of real information until the threshold of political procrastination is breached. At that point a policy is rapidly developed and instituted; its design reflecting the bargaining power of various stakeholders and the prevailing paradigm of instrument choice. There is no reason to believe industry will know how to implement the policy efficiently. There is no reason to believe that policymakers will have set appropriate targets or chosen an appropriate regulatory instrument. In other words, after years of “debate” there will be a policy with no guarantee of effect, efficiency and equity.

Most environmental regulations (except bans on specific products and processes) involve a process of periodic review and revision of targets and measures. The initial step is often the most contested stage of this process. But depending on the scale of first effort we need not get the policies right the first time. However, it would be good to have an adaptive learning strategy generating the information necessary to improve policy design at each successive step. Thus, a proposal for an adaptive management approach to environmental policy. Adaptive management hinges on evaluation of costs and benefits and feedback of that information to refine the next step in management.

Adaptive management is well-established in ecology and has been applied to natural resource management issues (Gunderson, Holling et al. 1995). I propose refining the traditional model of adaptive management to manage environmental regulations. The proposed approach aims to exploit a synergy in heterogeneity of firms and properties of different regulatory instruments.

I believe firms can be classified into three groups:

- Innovators: love to explore new technologies, management approaches, market opportunities. Their success depends on first mover advantage and brand recognition.
- Followers: excel at taking ideas demonstrated to be successful by innovators and reproducing these at lower cost or modified to fill a wider range of market conditions.
- Foot draggers: give us a sense of history by being living examples!

In the preliminary debates about any proposed new regulations, the innovators are willing to explore possibilities, the followers do not know how they would fare and foot draggers actively resist change. The foot draggers will of course also be representing firms who are struggling in any competitive setting. Furthermore, the mechanics of representation and constituency politics will lead their concerns to receive particular attention. I believe this is *why* any proposed new regulation meets with a protracted battle of speculative *ex ante* studies variously touting unbearable costs and immeasurable benefits. Perhaps a way out of this impasse is to regulate different types of firms at different times and using different instruments.

Innovators, are often at the frontier of knowledge about possible adverse impacts of their own activity and keen to try out new processes and products. However, their own “experiments with

alternatives” is muted by fears of: a) grandfathered regulations being applied to a baseline after they have implemented their control strategies; b) developing technology that is later regulated as being inadequate; c) revealing the technology frontier but being pushed to implement standards beyond it. These concerns arise from the lack of trust between the industry and regulators. On the other hand, if innovators find new environmentally more beneficial processes, they could enjoy first mover advantage and appropriate rent from follower industries adopting their intellectual property.<sup>5</sup>

Clearly, if regulators were to address the concerns noted above, they could have a powerful and most knowledgeable partner in searching for better approaches to meeting regulatory objectives of mutual interest. This mode of operation has already been shown to succeed during the Montreal Protocol process. The technical committee was comprised of leading scientists from competing industries and they often identified solutions to control of particular CFCs that would rely on innovations by one or other firm. The policy committee was willing to move on such information even when it would grant monopoly power on particular products to particular industries (The Social Learning Group 2001). We can use this experience as a model for Phase I of an adaptive control regulation.

In Phase I, *Innovator Firms* partner with regulators to identify feasible paths to meeting regulatory objectives. When successful, they would reveal what is achievable and the different paths to that achievement and their costs. In doing so they would also have created intellectual property whose value could be realised in Phases II & III. Thus, a successful Phase I leads to innovator firms joining forces with regulators to promulgate the next phases of the regulations.

In Phase II, *Follower Firms* will face a known feasible target, and have the benefit of information generation in Phase I about the costs and performance of alternative approaches to meet it. *Follower Firms* excel at identifying which technology to adopt and how to reduce its costs. Clearly, a market-based setting for a set period will encourage development of improved alternatives and falling costs of controls. By the end of Phase II a suite of control approaches will have emerged as winning and economical approaches capable of meeting the regulatory objectives.

In Phase III, *Foot-dragger Firms* will face command and control regulations requiring adoption of the best available technology.

In this scheme, firms face different risks and rewards for participation in different phases of regulations. At one extreme, firms occupied with other challenges wait to the end of technology development and regulatory cycle, but pay IP rights to innovators and follower firms. At the other extreme firms are created by venture capitalists to find innovative solutions to the policy objective and reap the benefits of discovering commercially valuable intellectual property.

The three Phases are repeated again, when new policy objectives are identified (e.g., modified standards or controls on new sources of concern). If the timing of these phases and repetitions are coordinated with the rate of technical change and capital turnover in the industry, the costs of the regulation can be further reduced. If the “clock” for each phase is set to the history of a particular firm’s participation, the costs can be reduced even further. In such a case, firms who are innovative may end up

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<sup>5</sup> Some industry leaders neither need risk under-writing nor ask for IP rents when addressing a critical environmental control challenge. After learning of significant SF<sub>4</sub> and S<sub>2</sub>F<sub>6</sub> emissions from aluminium smelters Paul O’Neil then CEO of ALCOA instructed their R&D labs to find a control strategy. Within 6 months, ALCOA not only had a solution that improved smelter productivity while eliminating SF<sub>4</sub> and S<sub>2</sub>F<sub>6</sub> emissions, they gave away the technology to other aluminium smelting establishments gratis [per. comm. Paul O’Neil March 1999].

accelerating their own capital turnover schedule in order to keep first mover advantage. Furthermore, each firm will know when they will have controls forced on them.

I should note that Phase I experiments may fail to identify practical or economical approaches to meeting policy goals. This failure will inform the basic question of desirability of this policy objective before committing the whole economy to a fruitless quest. It is far better to learn about this with a small group of willing industry vanguards, with agreements providing indemnity should an experiment fail.

A further advantage of such a staged and adaptive approach to regulation is that specific experiments can be designed to address a wide range of unknowns about policy design. For example, low value carbon intensive products are not thought of as readily traded goods because of high transportation costs. An experiment with leading cement or potash manufacturing firms would permit exploration of GHG control options with more control over direct trade impacts. An evaluation of the experiment would not only reveal the frontier of possibilities in GHG controls for cement and potash manufacturing, it would also reveal the validity of assumptions about the impact of regulations on direct and indirect trade impacts.

The obvious concern to initiating this approach to regulation for climate change is proximity to the first commitment period of the Kyoto protocol. Over the past 5 years some countries and firms have experimented with different aspects of GHG controls, but none have done so systematically. No one has laid out a clear timetable of regulatory experiments and evaluative criteria. Doing so, would not only have avoided protracted uninformed debates, it would have removed uncertainties about the regulation and its implementation. In my view, there is greater downside of bad public policy promulgated to meet the Kyoto timetable than shame in developing sound strategies for GHG controls two to five years later. The proposal here is not an abrogation of commitment to climate protection, but its affirmation through a sequence of well designed policies.

Unfortunately, GHG control strategies are such complex beasts that the chances of promulgating poor public policy are high. For example, in my view, the UK regulations imposing GHG taxes for private automobiles whether privately owned or an employee perk is a stroke of genius. It has demonstrated the tremendous power of unambiguous signalling. The program has doubled the new car market share for diesel cars (from 13% in 2000 to 26% in 2002). However, the policy has promoted early retirement of gasoline cars that emit less particulates by jumping the gun on much cleaner diesel engines and fuel (meeting Euro IV regulations) slated for introduction in 2005.

Beyond timing for GHG controls, we also face an uphill struggle in initiating such experiments as the antagonistic relationship between industry and regulators in so many countries has to be transformed into one of trust. However, I believe that if we adopt an adaptive regulatory framework it can lead to greater trust, well explored policy spaces, more innovation and less uncertainty.

## 7. CONCLUSIONS

For more than two decades there have been endless debates on the “costs of climate policy.” Fundamental uncertainties about these costs are not addressable through modelling. These are however open to exploration through careful experimentation. Furthermore, humans and firms are not homogenous objects. Leadership is the goal of some firms while others will only follow previously proven paths. All too often, policy design fails to utilize these features of society to full advantage. Just as there are Master Farmers among farmers, there are Master Industries within industry groups. Agricultural extension programs use Master farms as demonstration sites for what is possible. The same can be practiced among industry groups and environmental innovators.

Given the uncertainties in cost assessments and scope of needed GHG controls it is demonstrably a mistake to devise broad-based climate policies from the outset. In the long run it will be far less expensive to first engage in small-scale experiments designed to test and demonstrate different GHG control strategies and then promulgate the least costly solutions through regulations that sequentially promote: innovation, flexibility and diffusion of best technologies.

## 8. REFERENCES

- Azar, C. and H. Dowlatabadi (1999). *A Review of the Treatment of Technical Change in Energy Economics Models*. Annual Review of Energy and the Environment. R. Socolow. Palo Alto, California, Annual Reviews Inc. 24: 513-543.
- Barker, T. and N. Johnstone (1998). *International competitiveness and carbon taxation*. International competitiveness and environmental policies. T. Barker and J. Köhler. Cheltenham, Edward Elgar: 71-127.
- Barker, T. and L. Srivastava (2001). *Sectoral costs and ancillary benefits of mitigation*. Climate Change 2001: Mitigation - Contribution of Working Group III to the Third Assessment Report of the IPCC. O. Davidson, B. Metz, J. Pan and R. Swart. New York, Cambridge University Press: 561-99.
- Böhringer, C. and T. F. Rutherford (2002). "Carbon Abatement and International Spillovers." *Environmental and Resource Economics* 22(3): 391-417.
- Burtraw, D. (1996). "The SO<sub>2</sub> Emissions trading program: cost savings without allowance trades." *Contemporary Economic Policy* XIV(April): 79-94.
- Burtraw, D. (1998) "Cost Savings, Market Performance and Economic Benefits of the U.S. Acid Rain Program" RFF Discussion Papers, DP 98-28 rev, Washington DC.
- Dowlatabadi, H. (1998). "Sensitivity of Climate Change Mitigation Estimates to Assumptions About Technical Change." *Energy Economics* 20: 473-493.
- Dowlatabadi, H., R. Hahn, R. Kopp, K. Palmer and D. DeWitt (1993). "How Reliably Can Climate Change Impacts on Electric Utilities Be Assessed?" *Utility Policy* 3(July): 261-268.
- EIA (2001). *Residential Energy Consumption Survey*, Energy Information Agency, Department of Energy. 2001.
- Ellerman, D. A. and J.-P. Montero (1998). "The Declining Trend in Sulfur Dioxide Emissions: Implications for Allowance Prices." *Journal of Environmental Economics and Management* 36: 26-45.
- Felder, S. and T. F. Rutherford (1993). "Unilateral CO<sub>2</sub> reductions and carbon leakage: the effect of international trade in oil and basic materials." *Journal of Environmental Economics and Management* 25: 162-76.
- Gunderson, L. H., C. S. Holling and S. S. Light, Eds. (1995). *Barriers and Bridges to the Renewal of Ecosystem and Institutions*. New York, Columbia University Press.
- Harrington, W., R. D. Morgenstern and P. Nelson (2000). "On the Accuracy of Regulatory Cost Estimates." *Journal of Policy Analysis and Management* 19(2): 297-322.

- Hazilla, M. and R. J. Kopp (1990). "The Social Cost of Environmental Quality Regulations: A General Equilibrium Analysis." *Journal of Political Economy* 98(4): 853-873.
- Jaccard, M., R. Loulou, A. Kanudia, J. Nyboer, A. Bailie and M. Labriet (in press). "Methodological contrasts in costing greenhouse gas abatement policies: optimization and simulation modeling in micro-economic effects in Canada." *European Journal of Operations Research*.
- Jorgenson, D. W. and P. K. Wilcoxon (1990). "Environmental Regulation and US Economic Growth." *Rand Journal of Economics* 21(2): 314-340.
- Keith, D. (2002). *Towards a strategy for implementing CO2 capture and storage in Canada*. Ottawa, Environment Canada: 27.
- Lave, L. B. and H. Dowlatabadi (1993). "Climate Change Policy: The Effects of Personal Beliefs and Scientific Uncertainty." *Environmental Science and Technology* 27(10): 1962-1972.
- McCann, R. J. (1996). "Environmental commodities markets: "messy" versus "ideal" worlds." *Contemporary Economic Policy* XIV: 85-97.
- McKibbin, W. J. and P. J. Wilcoxon (1996). *The Wrong Way to Deal with Climate Change*, Brookings Institution.
- Morgenstern, R. D., P. W. D. and S. Jhih-Shyang (1998) "The Cost of Environmental Policy" RFF Discussion Paper, 98-36, Washington DC.
- Nordhaus, W. D. (1977). "Economic Growth and Climate: the Carbon Dioxide Problem." *American Economic Review* 67(1): 341-346.
- Porter, M. E. and C. van der Linde (1995). "Green and Competitive: ending the stalemate." *Harvard Business Review*(Sept-Oct): 120-134.
- Schipper, L., S. Bartlett, D. Hawk and E. Vine (1989). "Linking Life-styles and Energy Use: A Matter of Time?" *Annual Review of Energy* 14: 271-320.
- Taylor, D. K., R. Carbonell and J. M. DeSimone (2000). *Opportunities for pollution prevention and energy efficiency enabled by the carbon dioxide technology platform*. Annual Review of Energy and Environment. R. Socolow, Annual Reviews. 25: 115-146.
- The Social Learning Group (2001). *Learning to Manage Global Environmental Risks: Volume 1: A comparative history of social responses to climate change, ozone depletion, and acid rain*. London, MIT Press.
- Weber, C. and A. Perrels (2000). "Modelling Lifestyle Effects on Energy Demand and Related Emissions." *Energy Policy* 28: 549-566.
- Weyant, J. P. and T. Olavson (1999). "Issues in modeling induced technological change in energy, environmental and climate policy." *Environmental Modelling and Assessment* 4(2/3): 67-85.