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# Model, Model on the Screen, What's the Cost of Going Green?

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## Abstract

How much a policy is *expected to cost* and who bears the brunt of that cost play a significant role in the debates that shape regulations. We do not have a good track record of predicting costs and their ultimate distribution, but systematic reviews of past assessments have identified some of 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. Environmental stewardship is a long-term challenge and an adaptive regulatory approach promises to inform policy targets and improve controls through sequential regulatory phases that promote: innovation, flexibility and diffusion of best technologies.

**Keywords:** cost estimation, climate policy, modelling, adaptive management

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# Model, model on the screen, what's the cost of going green?

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## 1. Introduction

In many issues, national politics determine predisposition to specific policies and their implementation. In the United States of 2004 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 was worthwhile more than a quarter century ago (Nordhaus 1977). Unfortunately, from 1977 to 1997 when the Kyoto Protocol was struck there was no systematic exploration of the technical, institutional, and economic dimensions of GHG controls (other than through modeling) in order to inform basic issues such as regulatory design, financial mechanisms, achievable targets, and costs.

Our key concern is that *modeling* whether bottom up or top down is unlikely to reveal costs and barriers with sufficient detail and accuracy to guide policy. This paper is about what has been learned through models, analogues in regulations, and relevant case studies. It ends with a suggestion about ways forward in climate mitigation and other initiatives in environmental regulations where relevant experience is too scarce and uncertainties too large.

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In Europe, the resolve to address other structural changes, such as the severe decline of coal mining 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 other national priorities. Nonetheless, as we contemplate steps toward and beyond the first compliance period of Kyoto *expected* cost and benefit estimates continue to drive climate policy design and timing. But what relevant experience are these expectations based on?

In the decade of 1992–2002 a number of “GHG initiatives” were adopted in various countries but few if any have been systematically evaluated for efficacy of design. Those that did receive some attention (e.g., carbon pollution taxes in Sweden) were often singled out for their notoriety as being creatures of political posturing rather than designed to protect the environment or gather information on how to control GHG emissions.

The absence of systematic regulatory explorations of response possibilities handicaps regulators, firms and analysts offering insights about policy design. Furthermore, when it comes to regulating a new problem domain analogues are likely to be misleading. For example, many have used experience with energy crises of 1973 and 1979 as a basis for climate policy assessment. However, these are poor equivalents most fundamentally, because a crisis is not equivalent to a well-announced policy with a specific goal. The energy crises were surprise events that precipitated energy policies in many OECD countries. But our 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 response to climate change.

### **1.1 Shortfalls of modeling**

As a consequence of this lack of direct experience, today’s *predicted* assessments of the cost of climate policy at the level of firms, households and the economy are almost exclusively based on modeling exercises. 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. 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.

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<sup>4</sup> and the most detailed top down models are largely bereft of non-economic determinants of choices<sup>5</sup>.

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 modelers 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. The validity of modeling results (beyond the very obvious insights which are known even in the absence of models) is questionable and reflects initial assumptions as opposed to a new revelation.

## **1.2 Lessons from past environmental regulations**

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

Ideally, climate policy should: stimulate innovation and engender continuing support. As noted earlier, neither induced technical change nor preference and behavioral changes are well handled in models of any kind. These are greater challenges as the time horizon for analysis extends to century long simulations typical of climate studies. Furthermore, economic analyses often focus on first order costs and benefits of policy. The higher order linkages were the major motivation for developing integrated assessments of climate change (Dowlatabadi and Morgan 1993a; Dowlatabadi and Morgan 1993b). However, it is unrealistic to expect any effort to fully capture the myriad second and higher order impacts of climate policy—even when these effects may collectively be much larger than the first order impacts. However, public support and the

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<sup>4</sup> Prior to 1997 models did not include industrial carbon separation & sequestration as a mitigation option. This is not even a new technology, but a well-known set of technologies used to address a new challenge.

<sup>5</sup> Even the most behaviorally 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 society.

overall economics of climate policy will be function of all the policy impacts and not just first order analyses of policy costs and benefits.

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 *predicted* and *actual* 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 proposes an adaptive management framework to address the unknowns and develop smarter sequential policies.

## **2. Two challenges in cost estimation**

In traditional pollution control, there has been a clear distinction between compliance and production costs at the firm level. In GHG controls, the changes are so fundamental that it seems unlikely that compliance with deep GHG controls will be possible in the absence of process changes. Furthermore, cost estimates of regulations are usually associated with a particular target and timetable. Both the target and the timetable rely on a predicted baseline of activity and emissions profile. These are always uncertain and subject to being changed by the policy itself.

Firm-level costs are critical to their decisionmaking and shape their responses to proposed regulations. However, in trying to evaluate the broader welfare impact of public policy, we need to move the “boundary” of where costs (and benefits) 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. Their determination present significant challenges conceptually and empirically.

### **2.1 Boundary**

If a firm is asked to control a 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 control cost, all else held constant. 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 differing from 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 costs of a product (now associated with less pollution) is reflected in the economy as a whole. Depending on the relevance of this product to the provision of other goods and services in the economy, and the 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).

For climate policy we need to consider firm-level compliance costs versus firm-level total costs versus 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 four.

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 four-digit SIC level, and found that a) on average, the compliance costs and changes in production costs were not significantly different; b) on average, \$1 in pollution control costs leads to a rise in production costs of 81¢; and c) 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 it is 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, we 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 to 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. When capital investment cycles in different countries are out of synch (e.g., steel in Korea, Japan, Germany and the United States), the imposition of synchronous international regulations can lead to differential competitive outcomes internationally.

## **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 counterfactual 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, and so on. All of this information is needed in order to arrive at an accurate estimate of the *cost* of a policy.

While acknowledging parameter uncertainty is now common in modeling, structural uncertainties—i.e., how we model the way the world works—is less frequently explored. 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; or e) all the above. Each of these models of technical change would yield distinctly different baselines and responsiveness to specific policy initiatives. For example, a model of autonomous technical change would not have technical change respond to climate policy, R&D investments, or the shadow price of GHG. In two studies estimating the cost and efficacy of climate policy, one of the authors has shown how structural uncertainties are critical to cost estimation (Dowlatabadi 1998; Dowlatabadi, Hahn, Kopp, Palmer and DeWitt

1993). 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 labor 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 policymaker 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 economies 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 policy analysis makes 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 “modeled 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. Our favorite model is (M9) but we are not able to offer solid justification for why it is superior to another model, e.g., M5. Much of our modeling 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 to address key uncertainties about household, firm, and economy-level responses to specifics of policy. We shall return to this point in section six.

### 3. Lessons from comparison of *predicted* and *actual* cost estimates

Discussions of policy costs cannot 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 assessments of status quo and control cost estimates. It would be equally inappropriate to consider all industry opponents of environmental stewardship and all government agents dispassionate protectors of nature.

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>6</sup> The subjectivity inherent in pre-regulation debates is reflected in government cost estimates being 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 U.S. government (and others) has begun Regulatory Impact Assessments (RIA), collecting data that can be used to assess the validity of such criticism.<sup>7</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 were overestimated, versus 14% of cases where emissions were underestimated.

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<sup>6</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>7</sup> In September of 1993 US Executive Order 12866 mandated Regulatory Impact Assessment (RIA) for regulations costing over \$100 million annually. This has provided an opportunity to systematically review different regulations and try to understand factors that may have biased *predicted* cost estimates of proposed policies.

- In 50% of cases unit costs of reduction were overestimated versus 21% underestimated unit costs.
- Accuracy of predicted estimates of baseline emissions, unit costs, and total costs improved through time.
- Where flexible and incentive-based regulations were employed, baseline emissions were predominantly underestimated and unit costs overestimated. 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%.<sup>8</sup>

We 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 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 that GHG controls present a special case where *predicted* costs are systematically underestimated 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 emissions 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). We turn to a closer examination of the most celebrated and successful of these regulations in search of further insights.

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<sup>8</sup> Unfortunately, the U.S. regulatory history does not permit separation of the influence of flexibility and incentives on costs.

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

Six factors can be demonstrated to have led to predicted cost estimates that were too high:

- 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 overestimated. 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>9</sup>
- There was an incorrect assumption of fuel type inflexibility for existing power plants. Namely, units burning high-sulfur bituminous coals were thought to be incapable of operating on low-sulfur sub-bituminous coals or blends of these fuels.
- 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 predicted assessments were made. This has permitted fuel switching and expansion of generation away from coal.
- There was an incorrect assumption about the cost of delivering low-sulfur coals from mines in western U.S. 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.

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<sup>9</sup> For example, the rise in market share of Korean steel and car industries was driven by aggressive industrial and export policies, not the U.S. 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.

- 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 *predicted* projections.
- Emissions permits provided time flexibility eliminating the need to invest in spare scrubber units.

The first four factors show that baseline emissions were in error. These errors led to overestimation 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 desulfurization to grow competitive with low-cost, low-sulfur coal. Finally, permits can be designed to cover a broad enough time/source interval to eliminate the need to spare scrubbers to operate while other units are being maintained. This regulatory flexibility alone can save 20+% in capital costs of pollution equipment.

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

- Many comparisons have jumped the gun comparing *predicted* 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 emissions controls are imposed in Phase II.
- Predicted cost estimates did not reflect the fine structure of the regulation as implemented.
- The permit prices (used as the proxy for actual 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. Predicted 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 predicted 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 exuberant economic growth.<sup>10</sup> 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-sulfur coals in the U.S.). 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

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<sup>10</sup> The reader should note that here, the governments' need to project a rosy economic future leads to higher GHG emission estimates. This increases the projected adverse impacts of climate change to follow and heightens the need for mitigation measures.

attractive, especially where there is water scarcity (Taylor, Carbonell and DeSimone 2000).

#### 4. Political economy: trade and leakage

The majority of the discussion above has focused on the energy industry. However, GHG emissions limits will influence factor inputs to many other industries and have 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 (Böhringer and Rutherford 2002; Felder and Rutherford 1993; McKibbin and Wilcoxon 1996). There are political factors shaping details of policies that economists know to be inefficient. These details are rarely modeled and they can bias *predicted* estimations of policy costs and effectiveness.

Let us take the example of Canada. Not only is it the most open economy in the OECD, its economy is captive of the U.S. market with 87% of exports going there (Statistics Canada 2002). Canada is wrestling with the challenge of designing and implementing policies for meeting its emissions target under Kyoto. Meanwhile, the U.S. 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 Canadian 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 (Government of Canada 2002). 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 United States.

U.S. 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 U.S. 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, if largely export oriented, risk bankruptcy 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 on Crown Lands were too low, thereby making Canadian processed lumber exports unfairly subsidized.<sup>11</sup> This was used to unilaterally assess a 29% countervailing duty on Canadian lumber exports to the United States. The duty revenues have been accumulated and may be partially or wholly passed on to U.S. lumber producers, “to compensate them for unfair 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 lost in Canada and new sawmill investments moved to the United States.

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 *predicted* costs of policy on export-based industries is likely to be severely underestimated. Consider again, the example of the U.S.-Canada market. Firms with

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<sup>11</sup> Most lumber from Crown lands must be processed before being exported.

U.S. and Canadian facilities will be given *free* 85% of their GHG emissions limit in Canada as tradable permits. What is to stop them from selling these permits and moving production to the United States? Their bottom line would be improved; net Canadian emissions would be lowered; meanwhile emissions worldwide would not have declined *and* 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 GHG control policy.

## 5. Costs of policy to households

Much of the foregoing discussion has focused on estimating the cost of policies at the firm and economy levels. By and large, these are far better studied/modeled 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 (Shui and Dowlatabadi 2003). This alone highlights the importance of household behavior in response to policy (Schipper, Bartlett, Hawk and Vine 1989; Weber and Perrels 2000).

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

Presumed *high personal discount rates* have long been used (Jaccard, Loulou, Kanudia, Nyboer, Bailie and Labriet in press) to represent more realistically the observation that decisionmakers do not respond to cost saving opportunities when returns to such informed

decisions *should* be sufficient. While this is a convenient modeling trick, we have been interested in learning how far different decisionmakers stray from *economically rational* behavior. 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) we 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?

Upon analyzing data on energy expenditures from a representative sample of 5900 U.S. households (US DOE Residential Energy Consumption Survey, 1997) we found that:

- 76% of households report being aware of energy savings information and labels on household appliances, yet more than 64% of U.S. households do not use guides to energy savings when purchasing energy using appliances.
- In the 95% of households who pay their own energy bills, energy efficiency information guides the appliance choices of 37% of households.
- In the 5% of households who receive public assistance with their energy expenditures, only 22% use energy efficiency guides in appliance purchases.
- 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 us that perhaps the assumption that households have the *freedom to choose* mischaracterizes the opportunities facing a significant fraction (at least in the United States). 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 income, 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 our 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. DeCanio (DeCanio 1998) uses the Greenlights database of the US EPA to study more than 3000 projects where firms could voluntarily adopt more efficient lighting options. He finds that organizational factors are almost as important as economic factors in explaining the adoption of more efficient lighting strategies. Boyd (Boyd 1998) uses case studies in the chemicals industry where process changes were required to adopt pollution prevention strategies to explain why the details of process changes and co-production and management of chemicals so much more complex than might be captured in a simple economic analysis of control costs.

## 6. A strategy for regulation when costs are unknown

Whenever there is significant uncertainty about costs of a policy, there are endless *duels of perspectives* with nary an addition to the factual basis supporting dichotomous assertions. Our 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<sup>12</sup> 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.

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<sup>12</sup> Even when a regulation is implemented despite powerful opposition, it often contains incentives and exemptions for key stakeholders.

Most environmental regulations 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. A simple metaphor is that of chess versus jigsaw puzzles. Rather than trying to get the outcome right the first time (as in jigsaws), winning in chess is understood on the principle level (i.e., checkmate), where the player has no idea what pattern of success will ultimately prevail given the infinite winning combinations. In the meantime, the chess player moves one piece at a time, attempting to limit exposure to risk and test alternative strategies for winning, all the while learning from past moves to plan future moves. 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 and Light 1995). Holling and Gunderson (2001) have further expanded the concept in their work on “panarchies”—systems of hierarchies and adaptive cycles, where a healthy system invents and experiments, benefiting from inventions that create opportunity, while insulating itself from those that destabilize. They describe sustainable development as requiring both a conserving (sustainable) and a creative (development) component—conserving in that adaptive capacity must be maintained, and creative in that opportunity must continually be created.

Human systems have the potential to create resilient systems because of foresight and intentionality, communication, and technology. Furthermore, for linked ecological-social-economic systems, slow variables, multistable behaviors, and stochasticity, cause active adaptive management to outperform optimization approaches that seek stable targets. Thus, it makes sense to harness this ability and refine the traditional model of adaptive management to manage environmental regulations that encourage resilience and adaptation. The proposed approach differs, however, in that it aims to exploit a synergy in heterogeneity of firms and properties of different regulatory instruments.

We believe firms can be classified into three groups:

- Innovators: love to explore new technologies, management approaches, and 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.
- Laggards: give us a sense of history by being its 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 laggards actively resist change. The laggards will of course also represent firms who are struggling in any competitive setting. Furthermore, the mechanics of representation and constituency politics will lead their concerns to receive particular attention. We believe this is *why* any proposed new regulation meets with a protracted battle of speculative *predicted* 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” are 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>13</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

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<sup>13</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 aluminum smelters, Paul O’Neill, then CEO of ALCOA instructed their R&D labs to find a control strategy. Within six 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 aluminum smelting establishments gratis (personal communication Paul O’Neill March 1999).

particular CFCs that would rely on innovations by one or the 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).

Badaracco's (1985) description of vinyl chloride (VC) regulation in the 70s also provides a roadmap for collaborative policy experiments between business and government. When the link between VC and cancer was made, drastic action was required literally overnight. Japan, Germany, the UK, and France set out on a policy course marked by: a) cooperation/negotiation with and involvement of all direct stakeholders, b) middle management involvement, c) regulations promulgated only after compliance was ensured, d) no lawyers or judicial review, e) private meetings relying on informal networks, f) an open sharing of information, g) flexible timelines, h) decisions that followed technology, and i) timelines that were open and flexible. The US, on the other hand, set a course of secret deliberations, conflict and rhetoric, sour relations, plenty of lawyers, and standards promulgated too quickly exceeding technical capacity and assuring further conflict and disappointment.

The outcomes were a stark contrast. The collaborative approach pursued a completely different path of legitimacy by ensuring parties had a much stronger stake in a successful outcome, and legitimacy of the outcome was increased through shared responsibility. By moving cautiously, patiently and privately, government agencies secured several advantages: a) they gained full access to industry expertise, b) they shared political risks, c) they resolved a difficult problem with minimal frustration, d) they created a standard that was more effective, e) they set a precedent for future cooperation, f) they were able to achieve compliance with reduced costs, and g) they were still able—had the process failed—to resort to legislation.

A generation later, the lessons from this process are still pertinent: cooperation can work well for regulation when key parties are effectively represented, when the main task is clearly defined and goals widely shared<sup>14</sup>, and if gathering and assessing information can reduce critical uncertainties. The collaborative approach had adaptive management principles at its core, where each stage was approached with information sharing, moderate action, review, learning, and then further planning for reductions. This reduced surprises and frustrations. We can use these two experiences as a model for Phase I of an adaptive control regulation.

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<sup>14</sup> Although participating businesses were not all “innovators” in the strict sense, all parties did share a commitment to drastic reductions of VC exposure in the workplace.

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 realized 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 generated 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 control costs. 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, *Laggard Firms* will face command and control regulations requiring adoption of the best available technology. Dealing with laggards at the end of the process ensures they do not scuttle creativity and innovation during Phase I through intense lobbying efforts.

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 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.

We 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.

Although governments often claim they take an adaptive management approach to regulations, this is misleading for two reasons. First, many government-business partnerships are often composed of firms from across the adoption spectrum, representing innovators, followers and laggards. This does nothing to foster a collaborative environment, but instead entrenches secrecy as firms attempt to ensure a lowest common denominator policy target is set. Second, “adaptive management” initiatives are typically voluntary, thereby removing the powerful incentives that promise returns for IP development and penalties for laggards (who essentially free-ride on innovators’ efforts). Neither factor has resulted in particularly successful outcomes.

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 five 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 a greater downside to 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 the authors’ 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 signaling. 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 and information sharing, well explored policy spaces, more innovation, less foot-dragging, 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 modeling. 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.

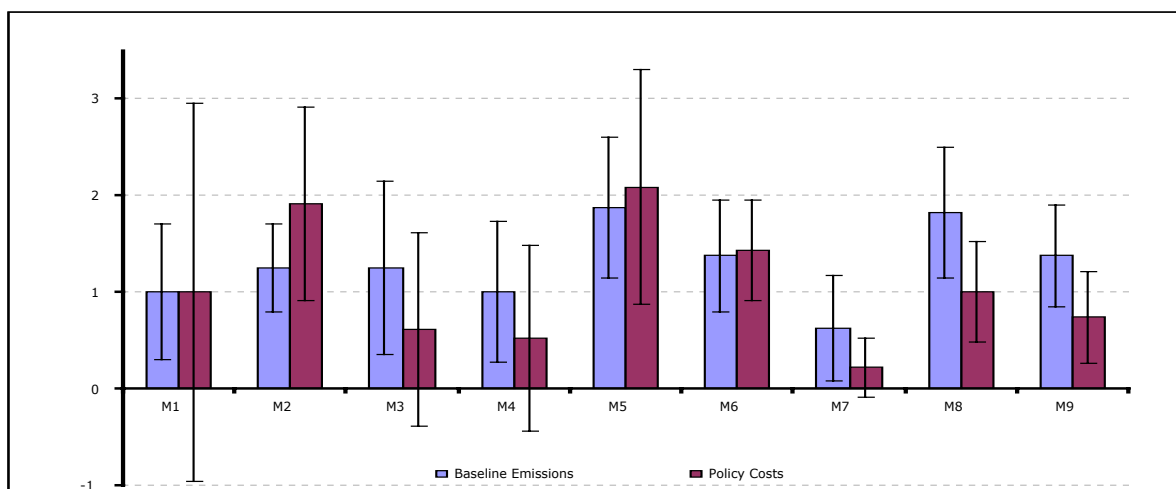
Given the uncertainties in cost assessments and scope of needed GHG controls, it is demonstrably a mistake to devise broad-based climate policies from the outset. In the long run it will be far less expensive to first engage in small-scale experiments designed to test and demonstrate different GHG control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

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Figure 1

Normalized emissions baselines and policy ( $\text{CO}_2 = 500 \text{ ppm}$ ) cost estimates using ICAM-3



The figure represents results for nine model structures (M1 to M9). Each model has different structural assumptions about the machinations of energy markets. These assumptions spanned issues from fossil fuel availability and pricing to technical change, learning curves, and responsiveness to policy and prices. Each model's parameters (and uncertainties) were estimated using the Bayes Monte Carlo procedure and U.S. energy and economics statistics from 1950-1995. The ICAM model variants were run 400 times to generate the expected emissions and control costs ( $\pm 1$  sigma uncertainties in these estimates). Finally, all emissions 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. The model structures assumed are:

Model Components	M1	M2	M3	M4	M5	M6	M7	M8	M9
<i>Will higher fuel prices lead to new oil &amp; gas discoveries?</i>	no	yes	no	no	yes	yes	no	yes	yes
<i>Is energy using technical progress affected by fuel prices &amp; carbon taxes?</i>	no	no	yes	no	yes	yes	yes	yes	yes
<i>Does the cost of abatement and non-fossil technologies fall with experience?</i>	no	no	no	yes	no	no	yes	yes	yes
<i>Is there a policy to transfer carbon saving technologies to non-Annex 1 countries?</i>	no	no	no	no	no	yes	yes	No	yes

## 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.
- Boyd, J. 1998. *Searching for profit in pollution prevention: case studies in the corporate evaluation of environmental opportunities*. Washington DC, Resources for the Future: 48.
- 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.
- DeCanio, S. J. 1998. The efficiency paradox: bureaucratic and organizational barriers to profitable energy-savings investments. *Energy Policy* 26(5): 441-54.
- 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.
- Dowlatabadi, H. and M. G. Morgan 1993a. Integrated assessment of climate change. *Science* 259(5103): 1813.
- Dowlatabadi, H. and M. G. Morgan 1993b. A model framework for integrated studies of the climate problem. *Energy Policy* 21(3): 209-221.
- 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.

- Government of Canada 2002. *Climate change plan for Canada*. Ottawa, Government of Canada: 75.
- 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 CO<sub>2</sub> 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.
- Shui, B. and H. Dowlatabadi 2003. Consumer lifestyle approach to US energy use and the related CO<sub>2</sub> emissions. *Energy Policy* in press.
- 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.