OPTIMAL EARLY ACTION ON GREENHOUSE GAS EMISSIONS

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3 January 2002

ABSTRACT

This paper argues that early action policies which focus on early actual emission reductions will tend to distort abatement investment decisions, and thereby inflate the national compliance cost of the Kyoto Protocol on greenhouse gas emissions. Compliance cost savings stem from well planned early action that may or may not yield early actual emission reductions. Thus, policies which target actual emission reductions, like "credit for early action" or an aggressive early "cap-and-trade" program, have the potential to be highly distorting. Simulation results from a five sector model calibrated to the Canadian economy suggest that the associated welfare losses could be many billions of dollars. The paper advocates the introduction of a very modest early cap-and-trade program (to capture early environmental co-benefits), coupled with trading in emission futures whereby permits for emissions in 2008 – 2012 are issued gradually between now and 2008, and allowed to trade freely. Such a system would create the price signals required to motivate early action.

Condensed version published in *Canadian Journal of Economics*, 2002

1. INTRODUCTION

As a signatory to the Kyoto Protocol on climate change, Canada has agreed to reduce its greenhouse gas (GHG) emissions during the period 2008 – 2012 to 6% below 1990 levels. That agreement will become legally binding if the protocol is ratified. Moreover, if the prevailing scientific consensus on the link between climate change and GHG emissions is maintained, future extensions of the protocol will likely mean that these reduced emission levels will have to be sustained for the foreseeable future.

Forecasts based on "business-as-usual" projections for the 2008 – 2012 period estimate that Canada is currently running at around 36% over the Kyoto target.[1] This looming "Kyoto gap" has raised serious concerns about the likely costs of meeting the target if early action (EA) is not taken to help smooth the transition. Shifting the Canadian economy to a growth path with one-third fewer GHG emissions, produced primarily from the production and combustion of fossil fuels, will require dramatic technological and behavioural adjustments. This adjustment process will likely be less costly if action is initiated well before 2008.

There are two main benefits from EA: compliance cost savings during the 2008 – 2012 commitment period; and early environmental benefits. Compliance cost savings stem from the fact that the cost of innovating and adopting new technologies can likely be reduced if the adjustment process is spread over a longer period. There are three main reasons for that. First, bottlenecks associated with capacity constraints can be eased if the adjustment process is more gradual. Second, sunk capital investments made in the years prior to 2008 can be adjusted to incorporate emission-reducing technologies at lower cost than if the same emission reductions are achieved in 2008 – 2012 by retrofitting or scrapping that capital. Third, learning effects associated with technological change mean that costs can be reduced if the changes are undertaken with prior experimentation.

It is important to note that many valuable types of EA will not necessarily yield significant emission reductions prior to 2008. For example, research investments aimed at innovating new types of fuel cell may not produce actual emission reductions for years; nor will early planning and investment in new hydroelectric capacity. This raises a critical distinction for the purposes of designing policy: EA versus early emission reductions. These are not the same thing. The actual emission reductions that an EA yields in the period prior to 2008 is

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[1] See Analysis and Modelling Group (1999).

unimportant in terms of Kyoto compliance cost savings because these reductions cannot be credited against the Kyoto target. This means that policies which create incentives for early emission reductions *per se* will not necessarily create the correct incentives for optimal EA, and can in fact be highly distorting.

The second main benefit from EA is reduced environmental damage. There are two components to this benefit. First, to the extent that emission reductions in the period prior to 2008 reduce the overall atmospheric stock of GHGs relative to business-as-usual levels, there will be less climate change. In practice, Canada currently accounts for around 3% of global GHG emissions; any unilateral reduction in those emissions prior to 2008 is likely to have only a minor effect on global climate change. Moreover, the benefit to Canada – as distinct from total global benefit – from that diminished climate change is likely to be minimal. Second, there are local air quality benefits associated with reductions in other pollutants that are often produced jointly with GHGs; particulate matter, precipitation acidifiers, and tropospheric ozone precursors are the most important of these pollutants. These “co-benefits” of GHG emission reductions are likely to be much more important in a Canadian context than any climate-related benefits from EA.

It is important to note that the environmental benefits of EA are due to the associated actual early emission reductions, while the compliance cost savings from EA are not. This has important implications for the design of EA policy. In particular, a single policy instrument will generally not be capable of inducing an optimal outcome along both these margins.

The purpose of this paper is to characterize the optimal adjustment process, and to assess in relation to that optimal solution the likely performance of the main EA policy proposals currently under consideration in Canada. A second purpose of the paper is to advocate a new policy approach that I believe dominates the existing proposals. I support my theoretical analysis with some dollar estimates of the potential cost of using the wrong policies, derived from a five-sector simulation model calibrated to the Canadian economy. These estimates point to potential costs measured in many billions of dollars.

The rest of the paper is organized as follows. Section 2 presents a simple theoretical model that forms the basis of the analysis. Section 3 characterizes the optimal EA solution in the context of the theoretical model. Section 4 presents a simple five-sector simulation model calibrated to the Canadian economy, the main purpose of which is to provide some indication of the dollar magnitude of the policy problem. Section 5 then assesses a variety of EA policies in the context of a domestic emissions trading program for the commitment period. Each policy is examined in terms of the theoretical model and the simulation model. Section 6 then introduces international emissions trading. Section 7 raises a number of important issues that are not addressed directly by the model. Section 8 summarizes the main results and presents some concluding remarks.

2. THE MODEL

Time is divided into two periods: the period prior to 2008, in which there are no internationally binding restrictions on GHG emissions (period 1); and the commitment period (2008 – 2012) in which Canada is bound by its commitment under the Kyoto agreement (period 2). There are N emitting entities. Let b_{it} denote BAU emissions for entity i in period t. This is the level of emissions that entity i would produce in the course of its normal operations in the absence of any deliberate action on GHGs. Let B_t denote aggregate BAU emissions in period t:

$$B_t = \sum_{j=1}^{N} b_{jt} \tag{1}$$

Let e_{it} denote actual emissions for entity i in period t, and let K_2 denote the total emissions budget in period 2 under the Kyoto agreement. If Canada is in compliance with the Kyoto agreement, then

$$\sum_{j=1}^{N} e_{j2} \leq K_2 \tag{2}$$

Compliance is henceforth assumed. Thus, $(B_2 - K_2)$ represents the “Kyoto gap”.

Abatement Actions

I distinguish between two types of action to reduce GHGs: technological abatement; and behavioural abatement. Technological abatement changes the basic relationship between economic activity and the associated level of GHGs. For example, converting to hydroelectric power generation reduces the volume of GHGs per kilowatt hour of electricity produced in the economy. In contrast, behavioural abatement achieves emission reductions through reductions in the level of economic activity, while leaving unchanged the basic relationship between that activity and the emissions it produces. For example, turning down the heat to cut electricity use reduces emissions but leaves the underlying technological relationship unchanged.[2]

A key distinction between behavioural abatement and technological abatement is the nature of the temporal relationship between the action and the associated emission reductions. By definition, behavioural abatement actions yield emission reductions in the same period in which they are undertaken. The same is not necessarily true of technological abatement; different types of technology investments yield different time profiles for emission reductions, due to investment lags and learning effects. The key implications of that diversity can be modeled effectively by assuming just two stylized types: "research & planning" (investment in knowledge creation); and "capital investment" (investment in physical capital). Research & planning undertaken in period 1 yields emission reductions only in period 2; capital investment undertaken in period 1 yields emission reductions in both periods.

Let x_{i1} denote research & planning by entity *i* in period 1, and let y_{i1} denote its capital investment in that period. The associated reduction in emissions in period 1, relative to BAU emissions in that period, is

$$r_{i1}(y_{i1}) = \alpha_{i1} y_{i1}^{1/2} \tag{3}$$

where α_{i1} is a non-negative parameter. Note that x_{i1} has no impact on emissions in period 1. Let y_{i2} denote capital investment by entity *i* in period 2. Then the overall reduction in emissions in period 2, relative to BAU emissions in that period, is

$$r_{i2}(x_{i1}, y_{i1}, y_{i2}) = [\lambda_{i1} x_{i1}^{1/2} + \theta_{i1} y_{i1}^{1/2} + \alpha_{i2} y_{i2}^{1/2}] \tag{4}$$

where λ_{i1}, θ_{i1} and α_{i2} are non-negative parameters. That is, r_{i2} is the amount by which the entity's emissions are reduced in period 2 due to the combined effect of research & planning in period 1, capital investment in period 1, and capital investment in period 2.

The relationship depicted in (4) reflects three key properties of early action. First, research & planning yields emission reductions only with a lag. Second, capital investment in period 1 yields ongoing emission reductions in period 2 (relative to BAU), but of a potentially different magnitude from the reductions obtained in period 1. That is, θ_{i1} and α_{i1} could have different values. The most likely scenario is one in which $\theta_{i1} > \alpha_{i1}$, reflecting learning effects

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[2] The distinction between technological abatement and behavioural abatement is undoubtedly less sharp in reality, but this approach to modelling the abatement process helps to provide a clear focus on the importance of

associated with the adoption of new technologies.[3] Third, *ceteris paribus*, emission reductions in period 2 due to capital investment are greater when that investment is spread between periods 1 and 2 than when it is concentrated in period 2 alone. This reflects the cost savings associated with spreading capital investment over time and thereby reducing the potential for bottlenecks in the economy due to capacity constraints.

Emission reductions not met through technological abatement must be met through behavioural abatement. The cost of behavioural abatement for entity *i* in period *t* is assumed to be quadratic in the amount of abatement undertaken:

(5) $$c_{it}(e_{it}) = \gamma_i z_{it}^2$$

where $z_{it} = [b_{it} - r_{it} - e_{it}]$ is behavioural abatement, r_t denotes the emission reductions associated with technological abatement, and γ_i is a positive parameter.

Environmental Benefits

Let δ_t denote the marginal environmental benefit from emission reductions in period *t*. In period 1 this includes environmental co-benefits from pollutants produced jointly with GHGs, and any domestic climate-related benefits. In period 2, only co-benefits are included because we are concerned only with measuring the cost of meeting the Kyoto target (the climate benefits of which may or may not exceed the cost). I henceforth refer to these environmental benefits simply as “co-benefits”. It is worth noting that GHG policy is a second-best approach to controlling co-pollutants. If co-pollutants were priced correctly according to their marginal damage then the technological relationship between GHG production and co-pollutants would be different, and δ_t would likely be lower. However, even with appropriate pricing it is likely that some co-pollutant production would persist, and co-benefits would still be positive.[4]

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distinguishing between EA and early emission reductions.

[3] Parry and Toman (2000a) also examine a model with learning effects but learning in their model stems from early emission reductions *per se*. This is the only link between EA and compliance cost savings in their model.

[4] It should also be noted that the relationship between GHGs and co-benefits is likely to differ across sectors and across geographical regions. However, I abstract from this point here and assume a simpler setting in which marginal co-benefits are uniform across sources.

3. OPTIMAL EARLY ACTION

The planning problem is to choose the amount and mix of abatement actions across the *N* entities to minimize the “Kyoto compliance cost”, defined here as the present value of abatement costs minus the present value of co-benefits. Thus, the cost minimization problem is

$$(6)\qquad \min_{\{x,y,e\}} \sum\nolimits_{j=1}^{N}(x_{j1}+y_{j1}) + \sum\nolimits_{j=1}^{N}\gamma_j[b_{j1}-r_{j1}(y_{1j})-e_{j1}]^2 - \delta_1\sum\nolimits_{j=1}^{N}(b_{j1}-e_{j1})$$

$$+\beta\Big(\sum\nolimits_{j=1}^{N} y_{j2} + \sum\nolimits_{j=1}^{N}\gamma_j[b_{j2}-r_{j2}(x_{1j},y_{j1},y_{j2})-e_{j2}]^2 - \delta_2\sum\nolimits_{j=1}^{N}(b_{j2}-e_{j2})\Big)$$

$$s.t. \qquad \sum\nolimits_{j=1}^{N} e_{j2} \le K_2$$

where $\beta \in [0,1]$ is the discount factor between periods 1 and 2. Note that if the marginal co-benefits of reducing GHG emissions in period 2 are sufficiently large, as measured by δ_2, then in principle it could be optimal to set aggregate emissions in period 2 to a level *below* the Kyoto target. In reality this is a remote possibility. I therefore focus on the case where the Kyoto constraint is binding at the optimum. The associated solution is given by equations (7) – (11):

$$(7)\qquad x_{i1}^{*} = \left[\frac{\beta\lambda_{i1}\left[B_2 - K_2 - \delta_1\sum\nolimits_{j=1}^{N}\left(\frac{\alpha_{j1}\theta_{j1}}{2}\right)\right]}{\sum\nolimits_{j=1}^{N}[\alpha_{j2}^2 + \beta(\lambda_{j1}^2+\theta_{j1}^2)] + \sum\nolimits_{j=1}^{N}\left(\frac{1}{\gamma_j}\right)}\right]^2$$

$$(8)\qquad y_{i1}^{*} = \left[\frac{\delta_1\alpha_{i1}}{2} + \frac{\beta\theta_{i1}\left[B_2 - K_2 - \delta_1\sum\nolimits_{j=1}^{N}\left(\frac{\alpha_{j1}\theta_{j1}}{2}\right)\right]}{\sum\nolimits_{j=1}^{N}[\alpha_{j2}^2 + \beta(\lambda_{j1}^2+\theta_{j1}^2)] + \sum\nolimits_{j=1}^{N}\left(\frac{1}{\gamma_j}\right)}\right]^2$$

$$(9)\qquad e_{i1}^{*} = b_{i1} - r_{i1}(y_{i1}^{*}) - \frac{\delta_1}{2\gamma_i}$$

$$(10)\qquad y_{i2}^{*} = \left[\frac{\alpha_{i2}\left[B_2 - K_2 - \delta_1\sum\nolimits_{j=1}^{N}\left(\frac{\alpha_{j1}\theta_{j1}}{2}\right)\right]}{\sum\nolimits_{j=1}^{N}[\alpha_{j2}^2 + \beta(\lambda_{j1}^2+\theta_{j1}^2)] + \sum\nolimits_{j=1}^{N}\left(\frac{1}{\gamma_j}\right)}\right]^2$$

$$(11) \qquad e_{i2}^* = b_{i2} - r_{i2}(x_{i1}^*, y_{i1}^*, y_{i2}^*) - \left[\frac{B_2 - R_2(x_1^*, y_1^*, y_2^*) - K_2}{\gamma_i \sum_{j=1}^{N} \left(\frac{1}{\gamma_j} \right)} \right]$$

where $R_2(x_1, y_1, y_2) = \sum_{j=1}^{N} r_{j2}(x_{j1}, y_{j1}, y_{j2})$.

Some key properties of the optimal solution emerge from these equations. First, a larger Kyoto gap, $(B_2 - K_2)$, calls for higher levels of technological abatement (of all types). Second, the optimal levels of technological abatement for a particular entity do not depend on the behavioural abatement cost parameter for that entity (γ_i), nor on BAU emissions for that entity, except insofar as these values affect the aggregate values for the economy as a whole. This result reflects the fact that marginal abatement costs (MACs) are equalized across entities at the optimal Kyoto budget allocation, regardless of entity-level BAU emissions or entity-level abatement cost functions. Third, optimal capital investment in period 1 is increasing in the size of co-benefits in that period, according to the extent to which that investment leads to early actual emission reductions (see the first term in (8)). Fourth, behavioural abatement in period 1 is warranted only on the basis of early co-benefits; note from (9) that if $\delta_1 = 0$ then $z_{i1}^* = 0$. Fifth, optimal behavioural abatement for a particular entity in period 2 is increasing in the size of the remaining aggregate Kyoto gap, $(B_2 - R_2 - K_2)$, and decreasing in that entity's own MAC parameter. Finally, the value of co-benefits in period 2 (as measured by δ_2) has no effect on the optimal abatement solution (assuming that the Kyoto constraint is binding at the optimum), though it does affect cost at the optimum.

4. SIMULATION

It should be stressed at the outset that the purpose of this simulation analysis is *not* to provide an estimate of the optimal EA strategy for the Canadian economy; there is not enough data available to conduct such an exercise. Indeed, the fundamental policy problem is to implement the optimal solution as a decentralized equilibrium *in the absence of information* on abatement costs. The purpose of the simulation is to establish a numerical benchmark against which various policies can be compared, under a variety of scenarios with respect to abatement costs, so as to provide some indication of the relative dollar magnitude of the potential distortions caused by those policies.

4.1 Calibration

The model is calibrated to the Canadian economy, disaggregated into five sectors: electricity generation, industry, residential and agriculture, transportation, and "other". Data from Analysis and Modelling Group (1999) and Energy Research Group (2000) was used to construct projected aggregate BAU emission levels for each sector for 2002 – 2007 (period 1) and 2008 – 2012 (period 2).[5] These values are presented in Table A1 in Appendix 1. Results from the Energy Research Group (2000) study were used to specify an economy-wide MAC in period 2, together with emission levels for each sector in period 2, under the least-cost compliance scenario. The Energy Research Group study estimates a commitment period least-cost MAC of \$120 (in 1995 dollars), based on a discount rate of 10% and no co-benefits. Their associated estimates for least-cost sectoral emissions are presented in Table A1. Particular values for α_1, θ_1, λ_1, γ and α_2 in each sector were then derived by specifying a set of relationships between these parameters (in order to set one type of abatement action as the numeraire) and then "backing out" the parameter values for each sector that produce a MAC of \$120 under the least-cost solution.

The specified parameter relationships are as follows: $\alpha_1 = \mathrm{A}\alpha_2$; $\theta_1 = \Theta\alpha_2$; $\lambda_1 = \Psi\alpha_2$; and $\gamma = \Gamma\alpha_2^{-2}$. The specific choice of capital investment in period 2 as the numeraire abatement method is arbitrary.[6] Setting different values for A, Θ, Ψ and Γ then produces simulated outcomes with different optimal mixes of abatement types, subject to yielding an overall MAC of \$120 in period 2 when $\delta_1 = 0$ and the discount rate is 10%.[7] Approaching the calibration problem in this way allows the performance of different EA polices to be examined under a maintained assumption with respect to least-cost MAC. The sensitivity of the results can then be tested with respect to that MAC.

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[5] The Energy Research Group (2000) study is one of two major microeconomic studies conducted for the National Climate Change Process (NCCP), the results of which are summarized in Analysis and Modelling Group (2000).

[6] Note that γ must be specified in terms of the inverse square of α_2 because behavioural abatement cost is expressed in equation (5) in terms of dollars per unit of abatement squared, while the technological abatement cost functions in (3) and (4) have been expressed in terms of abatement per dollar squared.

[7] A discount rate of 10% seems high but was maintained in the benchmark scenario for my simulations to ensure comparability with the NCCP results. Scenario 2 in my simulations considers a 5% discount rate; the results are not substantially different in terms of the performance of the different policies.

The benchmark scenario was calibrated with the following values: $\mathrm{A} = 1$, $\Theta = 1.1$, $\Psi = 1$, $\Gamma = 2$. These values imply that abatement due to research & planning and capital investment (in both periods) have the same marginal cost; that the learning effect associated with early capital investment is 10%; and that behavioural abatement is twice as costly as technological abatement. The implied values of α_1, θ_1, λ_1, γ and α_2 for each sector are presented in Table A1. Fixing these values and then resetting $\delta_1 = \delta_2 = 5$ yields the benchmark scenario.[8] Various alternative scenarios can then be examined to assess the relative performance of different policy options under a range of circumstances. Table A2 summarizes the 15 different scenarios examined.

4.2 Results (Benchmark Scenario)

The optimal solution is presented as Path 1 in Table 1. The results indicate that the least-cost Kyoto compliance cost is $29.8b (for the period 2002 – 2012), in present value terms and 1995 dollars. This is fairly consistent with the results from Analysis and Modelling Group (2000). Early technology investment accounts for $16.7b of that total, with $7.1b for research & planning and $9.6b for capital investment. This EA yields a reduction of 441 Mt in 2008 – 2012, or 49% of the Kyoto gap. The remaining gap is met through abatement actions undertaken during the 2008 – 2012 period itself. Note that there is only very modest behavioural abatement undertaken prior to 2008 ($0.02b or 7 Mt), because the co- benefits of early emission reductions are relatively minor ($5 per ton).[9]

It must again be stressed that this is not a prescription for optimal adjustment towards Kyoto; different scenarios generate different optimal solutions. In particular, a lower discount rate and a higher marginal co-benefit value generate a solution with more EA. Similarly, greater learning effects from early capital investment and greater relative productivity of research & planning also call for more EA. These sensitivity results are summarized in Table A3.

Table 1 also illustrates the costs of failing to take any EA (see Path 2 in Table 1). When all forms of EA are constrained to be zero, the total cost of Kyoto compliance is 103% (or $31b) higher than in the optimal solution. This difference is also dependent on scenario assumptions, but never falls below 77% in the 14 other scenarios examined (see Path 2 in Table A4).

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[8] The benchmark value of $5 for marginal co-benefits is based on Analysis and Modelling Group (2000).

[9] Note that MAC at the optimum is $118 rather than $120; this is due to the introduction of co-benefits.

5. IMPLEMENTATION WITH EMISSIONS TRADING

Optimal EA policy must be examined in the context of the regulatory regime that will be used to implement the Kyoto target in the commitment period. In this paper I focus on an emissions trading (ET) program for 2008 – 2012 under which permits are issued through an auction.[10]

5.1 The General Emissions Trading Framework

The supply of permits for emissions in period 2 is set equal to the Kyoto budget. Let p_2 denote the price of a permit in period 2, and let k_{i2} denote the number of permits awarded to entity *i* free-of-charge in period 2 (which may depend on e_{i1}, through a credit for EA policy). Let p_1 denote the price of emissions in period 1, established directly or indirectly through EA policy. Let k_{i1} denote any emissions allowance for period 1 granted free-of-charge to entity *i*. The problem for an emitting entity is to minimize the present value of its Kyoto cost through its choice of investments and emissions in periods 1 and 2, given its expectation of the permit price in period 2:

$$(12) \quad \min_{x,y,e} \; x_{i1} + y_{i1} + \gamma_i [b_{i1} - r_{i1}(y_{i1}) - e_{i1}]^2 + p_1[e_{i1} - k_{i1}] \\ + \beta\left(y_{i2} + \gamma_i [b_{i2} - r_{i2}(x_{i1}, y_{i1}, y_{i2}) - e_{i2}]^2 + p_2[e_{i2} - k_{i2}]\right)$$

Solving this optimization problem yields the following rational expectations equilibrium conditions:

$$(13) \quad x_{i1}^T = \left[\frac{\beta\lambda_{i1} p_2}{2}\right]^2$$

$$(14) \quad y_{i1}^T = \left[\frac{\alpha_{i1} p_1}{2} + \frac{\beta\theta_{i1} p_2}{2} - \frac{\beta\alpha_{i1} p_2 k'_{i2}(e_{i1}^T)}{2}\right]^2$$

$$(15) \quad e_{i1}^T = b_{i1} - r_{i1}(y_{i1}^T) - \frac{p_1}{2\gamma_i} + \left[\frac{\beta p_2 k'_{i2}(e_{i1}^T)}{2\gamma_i}\right]$$

$$(16) \quad y_{i2}^T = \left[\frac{\alpha_{i2} p_2}{2}\right]^2$$

$$(17) \quad e_{i2}^T = b_{i2} - r_{i2}(x_{i1}^T, y_{i1}^T, y_{i2}^T) - \frac{p_2}{2\gamma_i}$$

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[10] I examine the implications of grandfathered allocations in section 5.7.

where the “T” superscript indicates the solution under the ET equilibrium. A variety of EA policies can now be examined as particular specifications of this general framework. I begin with an ET program for period 2 with no ancillary EA policies.

5.2 Emissions Trading in Period 2 Only

The absence of any EA policies in period 1 means that $p_1 = 0$ and $k'_{i2}(e_{i1}) = 0$. Making these substitutions in (13) – (17) yields an equilibrium solution with the following properties:

Proposition 1

In the equilibrium under ET in period 2 only, if $\delta_1 > 0$ then
(a) research & planning in period 1 is too high;
(b) capital investment in period 1 is too low;
(c) behavioural abatement in period 1 is too low; and
(d) Kyoto compliance cost is too high
relative to the optimal solution. If $\delta_1 = 0$ then this equilibrium implements the optimal solution.
Proof. See Appendix 2.

The intuition behind these results is the following. If $\delta_1 = 0$ then there are no environmental benefits associated with actual emission reductions in period 1; the sole value of EA then stems from the compliance cost savings it creates in period 2. The ET program in period 2 ensures that MACs are equated across entities in period 2, and equated to the permit price in period 2, given the investments made in period 1. This in turn means that the private and social benefit of undertaking EA for any entity (in terms of abatement cost savings in period 2) is accurately reflected in the equilibrium permit price in period 2. Each entity then balances that private benefit with its own private costs of EA, across the different types of EA available to it, and so the marginal net social benefit of each type of action is equated across types within an entity, and across entities. Thus, ET in period 2, coupled with rational expectations of the associated equilibrium price, creates the correct incentives for EA. There is no need for additional policy measures.

This optimality result breaks down if $\delta_1 > 0$. In that case the social benefit of any action which creates actual emission reductions in period 1 exceeds the private benefit associated with abatement cost savings in period 2. This means that too little behavioural abatement is undertaken in period 1, and too little capital investment is made in period 1, since both actions yield undervalued emission reductions in period 1. This undervaluation of capital investment in period 1 means that a larger Kyoto gap remains at the beginning of period 2 than in the optimal solution. This in turn means two things. First, more abatement must be undertaken in period 2 (spread between capital investment and behavioural abatement); and second, the equilibrium permit price in period 2 is higher than in the optimal solution. This higher permit price induces more research & planning in period 1 than in the optimal solution. These combined distortions in the equilibrium EA choices necessarily lead to a higher Kyoto compliance cost.

Simulation Results

The magnitude of these distortions (for the benchmark scenario) is reported as Path 3 in Table 1. Note that the distortion is relatively minor; the Kyoto compliance cost rises by only 0.3%. This is due to the small value of marginal co-benefits in this scenario ($\delta_1 = 5$). However, even if marginal co-benefits are valued at $10, Kyoto compliance cost is still only 1% above least-cost (see scenario 5 in Table A4). Thus, ET in period 2 alone comes fairly close to implementing the optimal solution.

5.3 An Emissions Tax in Period 1

One possible solution to the distortions identified in proposition 1 is to introduce an emissions tax in period 1. If the tax is set equal to the marginal environmental benefit of emission reductions in period 1 (that is, δ_1), then the undervaluation of emission reductions in period 1 is corrected, and private and social benefits are realigned. Thus, we obtain the following result.

Proposition 2

The equilibrium under ET in period 2 coupled with an emissions tax in period 1 set equal to the value of marginal co-benefits in that period implements the optimal solution.
Proof. See Appendix 2.

Note that the emissions tax is simply correcting the undervaluation of co-benefits associated with early emission reductions; its purpose is not directly related to abatement costs in period 2.

However, the tax does reduce those costs indirectly by inducing a higher level of early capital investment.

5.4 Credit for Early Action

It is sometimes argued that an ET program only in the commitment period will not be enough to create the right incentives for EA, quite apart from any consideration of co-benefits. A variety of reasons are offered in support of that claim. Some are based on sensible arguments about technology spillovers, infant industry problems and uncertainty about the future policy regime (see section 7); others are self-serving overtures by vulnerable industries seeking government subsidies. In this section I examine the most widely advocated proposal to bolster incentives for EA: credit for early action (CEA).[11]

A CEA program awards an entity credits against its emissions in period 2 for actual emission reductions achieved in period 1 (relative to the BAU baseline).[12] In the context of the general ET framework, a CEA program can be represented by setting $p_1 = 0$ and

(18) $k_{i2} = \omega[b_{i1} - e_{i1}]$

where ω is the "exchange rate" for which emission reductions in period 1 can be exchanged for emission allowances in period 2. Thus, $k'_{i2}(e_{i1}) = -\omega$. Making this substitution in (14) and (15) reveals that the CEA acts like a price on first period emissions, with $p_1 = \beta\omega p_2$. However, this price is not a tax. The CEA program provides a subsidy for early emission reductions, where the subsidy is paid in terms of valuable credits against future emissions. This means that the CEA program is subject to the same textbook problem that plagues all subsidies: the distortion of non-marginal incentives. In the case of CEA, the problem lies with the distortion of BAU emissions: the CEA program creates a direct incentive for entities to undertake actions that inflate their BAU emissions. The potential even exists for the CEA program to induce an *increase* in the overall level of actual emissions. This problem with CEA programs is often misrepresented as a mere verification issue, the solution to which is a rigorous accounting system that would disallow credits for reductions that would have occurred anyway along the BAU path (so-called "anyway reductions"). This understates the problem. The true BAU path for an entity is private

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[11] See Credit for Early Action Table (1999) for NCCP thinking on the issue. For an example of a Canadian industry-sponsored proposal, see CEERP Collaborative (1999). For a discussion of some CEA proposals from the United States, see Nordhaus et. al. (1998) and Parry and Toman (2000b).

information; it is potentially shaped by every investment and operational decision that the entity makes, and it is unrealistic to expect that even the most rigorous CEA accounting system could discriminate between decisions that were motivated by CEA (at least in part) and those that were not. Some distortion of the BAU path is inevitable.

This moral hazard problem with CEA programs is outside the formal scope of this paper, since the determination of BAU emissions is not modeled. (For a good formal treatment of the problem see Parry and Toman (2000a)). The focus in this paper is on a second and equally important potential source of distortion associated with CEA programs, relating to their focus on crediting early emission reductions rather than early action more generally. The nature of this distortion is summarized in proposition 3.

Proposition 3

In the equilibrium under ET in period 2 and a CEA program in period 1, if $\beta\omega p_2 > \delta_1$ then

(a) research & planning in period 1 is too low;
(b) capital investment in period 1 is too high;
(c) behavioural abatement in period 1 is too high; and
(d) Kyoto compliance cost is too high

relative to the optimal solution. If $\beta\omega p_2 < \delta_1$ then the converse relationships hold. [13]

Proof. See Appendix 2.

The problem with CEA is its focus on early actual emission reductions. Any effective subsidy it pays in excess of marginal co-benefits creates a bias towards abatement actions that generate early emission reductions. (The converse is true for an effective subsidy less than marginal co-benefits). This means there is too little research & planning and too much early capital investment, since the former does not deliver immediate emission reductions while the latter does. Overall, the outcome is one with too much early action, with a mix of actions biased towards immediate emission reductions. In addition, the CEA program encourages excessive

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[12] Under some proposals, a modified BAU baseline is used, but the basic structure is as modeled here.
[13] In terms of primitive parameters, this threshold condition is

behavioural abatement if the effective subsidy is too generous relative to the value of marginal co-benefits.

Simulation Results

CEA proposals typically assume a unit exchange rate: $\omega = 1$. The simulation results for this policy are presented as Path 4 in Table 1. These results indicate that a CEA program for Canada could be very costly: the Kyoto compliance cost under the CEA policy is 17% (or $5b) higher than least cost. This welfare loss varies across scenarios but is never lower than 8%, and is sometimes over 20% (see Path 4 in Table A4). The compliance cost inflation is smallest when the learning effect of early capital investment is large (because the excessive early investment yields a large dividend in period 2; see scenario 9), and largest when early capital investment produces relatively large early emission reductions (see scenario 7). Note that 412 Mt worth of credits are awarded in equilibrium; this is 14.6% of the Kyoto budget.

It is interesting to calculate the effective abatement subsidy created by the CEA program. In the benchmark scenario, the effective equilibrium subsidy when $\omega = 1$ is $60. This means that marginal co-benefits would have to be $60 to justify a unit exchange rate. It is also interesting to ask what the exchange rate would need to be in order to yield an equilibrium effective subsidy equal to the actual value of marginal co-benefits ($5 in the benchmark scenario), and thereby implement the optimal solution as an equilibrium. The answer is 0.07. That is, each 100 tons of emissions reduced in the pre-2008 period would be rewarded with only 7 credits against emissions in 2008 – 2012. That "optimal exchange rate" is no higher than 0.14 in any of the scenarios examined.

5.5 An Early Cap-and-Trade Program

The CEA verification problem has lead some policy observers to suggest an early cap-and-trade program instead. The most widely cited and well annunciated proposal (for the United States) is by Kopp et. al. (1999). Such a program would introduce a modest cap on pre-2008 emissions combined with active trading. This idea has much to recommend it. First, if permits are

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$$\frac{2\beta\omega[B_2 - K_2]}{\beta\omega\sum_{j=1}^{N}\alpha_{j1}\theta_{j1} + \sum_{j=1}^{N}[\alpha_{j2}^2 + \beta(\lambda_{j1}^2 + \theta_{j1}^2)] + \sum_{j=1}^{N}\left(\frac{1}{\gamma_j}\right)} < \delta_1$$

auctioned (or grandfathered on the basis of pre-introduction emissions) then there are no verification problems. Second, it would allow the administrative and institutional structures needed for an ET program during the commitment period to be developed and fine-tuned prior to the point where the emissions cap is internationally binding. Third, it would begin to generate carbon price signals in the economy beyond just the anticipation of permit pricing in the commitment period.

The main disadvantage of an early cap-and-trade program is the difficulty associated with choosing the right cap on emissions. The right cap is one where the associated equilibrium permit price is equal to the marginal environmental benefit of emission reductions in period 1; that is, $p_1 = \delta_1$. Calculating that cap with any precision in practice requires more knowledge about marginal abatement costs than the regulator can hope to have. The risk of setting too strict a cap is that it produces an equilibrium permit price that is too high relative to marginal co-benefits, and thereby creates an excessive incentive to achieve actual emission reductions in period 1. The consequences of that distortion are the described in proposition 4.

Proposition 4

In the equilibrium under ET in period 2, and a cap-and-trade program in period 1, if the equilibrium permit price in period 1 is $p_1 > \delta_1$ then

(a) research & planning in period 1 is too low;

(b) capital investment in period 1 is too high;

(c) behavioural abatement in period 1 is too high; and

(d) Kyoto compliance cost is too high

relative to the optimal solution. If the cap on emissions in period 1 is set such that $p_1 = \delta_1$ then this equilibrium implements the optimal solution.

Proof. See Appendix 2.

The source of the potential distortion here is precisely the same as for a CEA program: the early cap-and-trade program can potentially place an undue emphasis on early actual emission reductions. Thus, even though the early cap-and-trade program does not suffer from the verification problems of CEA, it nonetheless has the potential to be highly distorting with respect to the amount and mix of early action.

Simulation Results

In the benchmark scenario the appropriate cap on emissions in period 1 would be 4118 Mt, which represents a 5.3% reduction from BAU emissions for that period, and a 14% increase over 1990 levels (on an average annual basis).[14] This might appear to be a fairly restrictive cap, given the modest value of marginal co-benefits in the benchmark scenario ($\delta_1 = 5$). However, it should be noted that even in the absence of a cap in period 1, emissions in period 1 under ET in period 2 alone would be 4135 Mt (a 4.9% reduction from BAU), due to the effect of early capital investment. Thus, any cap greater than 4135 Mt would not be binding. Of course, the optimal cap is lower for higher values of marginal co-benefits; at $\delta_1 = 10$ the optimal cap is 4102 Mt, but this is still only 33 Mt less than would be emitted in the absence of any cap.

Since the optimal cap cannot be easily determined by the regulator without the benefit of abatement cost information, it is worth examining how costly a mistake could be. I first examine a policy similar in magnitude to that proposed by Kopp et. al. (1999). They propose an elastic cap that generates an equilibrium price of US$25 per ton in 2002, and rising at 7% per year in real terms after that. The same price path in Canada would yield an average discounted price for the 2002 – 2007 period of about $40. The equilibrium in this case (for the benchmark scenario) is presented as Path 5a in Table 1. The cap required in period 1 to generate a price of $40 is 4004 Mt (which is 8% below BAU for 2002 – 2007 and 11% above 1990 levels on an average annual basis).[15] The Kyoto compliance cost under this policy is 7% (or $2b) higher than least-cost. This distortion reflects the fact that the value of marginal co-benefits is only $5 per ton while the price on emissions is $40 per ton. (The cost inflation falls to 6% when $\delta_1 = 10$). The source of the problem is the excessive incentive created by the early cap-and-trade program for early actual emission reductions; this is the same basic problem underlying a CEA program.

Table 1 also presents results for a much more aggressive early cap, labeled Path 5b in the table. This case sets an average annual cap in 2002 – 2007 equal to 1990 emissions levels. It serves to illustrate just how costly an injudicious choice of cap could be: the cost inflation over least-cost is 135% (or $40.3b) in the benchmark scenario. Moreover, this estimate is at the low end of the range of cost inflation values across scenarios (see Table A4).

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[14] The optimal cap is the value of aggregate emissions in period 1 under the optimal solution (see Path 1 in Table 1).

[15] Kopp et. al. (1999) estimate that a price of US$25 corresponds to an average annual cap equal to 10% above 1990 levels. Thus, the simulation results under the benchmark scenario are consistent with their estimates for the US.

5.6 Trading in Emission Futures

One of the merits of an early cap-and-trade program, notwithstanding its potential to distort EA decisions, is its potential to generate price signals for GHGs earlier than would otherwise be the case. The same is true of an early emissions tax. This could be of real practical value, given that equilibria in reality are likely not characterized by perfect foresight. However, the appropriate early emissions price is the value of marginal early co-benefits, and this does not convey any information to entities about the likely price of permits during the commitment period. For that reason I propose an early trading program based on emission futures.

The program would operate as follows. A very modest early cap-and-trade program, much like that proposed by Kopp et. al. (1999), but with a targeted equilibrium permit price in the range of \$5 to \$10, would be introduced in 2002 alongside a program for early trading of commitment period (CP) permits. That is, permits for emissions in 2008 – 2012 would be issued in 2002 and auctioned to entities in that year. Trading in CP permits would generate an equilibrium price that would provide a clear signal about the likely price of permits during the commitment period. In particular, if the price of CP permits in period 1 is q_1, then we would expect an equilibrium in which $q_1 = \beta\hat{p}_2$, where $\hat{p}_2$ is the market expectation of the permit price in period 2. In the benchmark scenario, this would imply an average price over 2002 – 2007 of about \$73.

As a practical matter, it would be judicious for the government to release CP permits gradually over time, perhaps around 400 Mt (or 14% of the Kyoto budget) per year over the period 2002 – 2007. This would allow a smooth evolution of the CP permit price, from around \$67 in 2002 to \$107 in 2007 (in the benchmark scenario), and minimize the potential for concentration in permit holdings by early movers taking advantage of the market infancy. Similarly, it may also be judicious to restrict international trades in the initial years of the program.

Such a program would create clear early price signals to motivate early action without encouraging an undue emphasis on achieving early actual emission reductions. The supplementary early cap-and-trade program would separately create incentives for appropriate early reductions based on co-benefits. While an early tax, set equal to marginal early co-benefits, would in principle be better for the latter purpose, the practical advantages of integrating the operation of emission futures trading with an early cap-and-trade program probably outweigh the theoretical arguments for an early tax. It is important however, that the early cap be very modest, consistent with the likely magnitude of marginal early co-benefits.

5.7 Grandfathering and Baseline Protection

Each of the policies discussed so far has involved the auctioning of permits. While there are many compelling economic arguments in favour of auctioning, there has nonetheless been a reluctance shown by the Canadian government to date to embrace auctioning. That reluctance is based partly on (largely unfounded) concerns about international competitiveness, and partly on purely political considerations. The alternative to auctioning is some form of grandfathering, whereby initial emission allowances are issued on the basis of historical, current or projected BAU emission levels. This approach to the allocation of permits raises some difficult issues with respect to protecting incentives for EA. In particular, if allowances for 2008 – 2012 for an entity are based on that entity's share of actual emissions over the pre-2008 period then there arises the potential for the creation of disincentives to undertake early actions that reduce actual emissions is the pre-2008 period. This is called a "baseline protection (BLP)" problem: the baseline against which period 2 allowances are awarded is not protected when an entity undertakes early action in period 1.

In the context of the general ET framework, the BLP problem can be represented by setting

$$(19) \qquad k_{i2}(e_{i1}) = \left[\frac{e_{i1}}{E_1}\right] K_2$$

in (12), where $E_1 = \sum_{j=1}^{N} e_{j1}$. The welfare properties of the associated equilibrium are described in proposition 5.

Proposition 5

In the equilibrium with grandfathering and no BLP,

(a) research & planning in period 1 is too high;

(b) the reduction in aggregate emissions in period 2 through capital investment in period 1 is too small;

(c) behavioural abatement in period 1 is too low (and potentially negative); and

(d) Kyoto compliance cost is too high

relative to the optimal solution, even when there are no co-benefits.
Proof. See Appendix 2.

The intuition behind these results is the following. An entity taking EA that reduces actual emissions in period 1 is penalized under the grandfathering scheme because that entity receives a smaller share of permits for period 2. This creates a disincentive to undertake early capital investment, and induces a shift towards research & planning instead, because the latter does not generate actual early emission reductions. It is important to note that this will not necessarily result in less early capital investment by *all* entities, nor even less early capital investment in aggregate, in an equilibrium with heterogeneous entities. In particular, the direct negative impact on early investment means that the equilibrium permit price in period 2 is higher than it would otherwise be, and the associated positive incentive for early investment can in principle be enough to offset the direct negative incentive for entities that have small emission shares; these entities may actually invest more in equilibrium than in the optimal solution. Only in a symmetric equilibrium can we be sure that all entities will invest less. However, the impact on aggregate emission reductions in period 2 is unambiguously negative in all cases.

In addition, the lack of BLP creates a disincentive for entities to undertake behavioural abatement in period 1, since this too reduces actual emissions in period 1 and thereby incurs a penalty in terms of emission allowances for period 2. Indeed, in the absence of any pricing of emissions in period 1, the equilibrium involves *negative* behavioural abatement in period 1; that is, emissions are increased beyond what would otherwise be profit-maximizing, for the purely strategic purpose of capturing a greater share of emission allowances in period 2. This strategic distortion creates a welfare loss comprising two parts: the cost of the distortion in the underlying economic activity; and any environmental damage associated with the inflated emissions.

Simulation Results

The simulation results for this policy (in the benchmark scenario) are presented as Path 6 in Table 1. Note that actual emissions in period 1 are much higher than in the optimal solution, but are nonetheless lower than BAU. This is due to the fact that emission reductions from early capital investment (though lower than optimal) offset the negative behavioural abatement. The cost of the distortion created by the grandfathering scheme is an inflation of 21% in the Kyoto compliance cost, or \$6.4b. In alternative scenarios that inflation figure ranges from 10% (in scenario 6) to 44% (in scenario 7); see Table A4. A higher compliance cost inflation is associated with a high productivity of early capital investment in terms of actual early emission reductions; this investment is heavily distorted when early emission reductions are penalized.

Baseline Protection Proposals

The solution to the BLP problem is in principle straightforward: auction the permits. That solution has not received a warm reception in Canada to date. There has instead been considerable debate about how to grandfather permits and at the same time provide BLP. Three main proposals have been examined by the NCCP: a "flat baseline" (which uses emission levels from 1990 or some other historical year as the baseline); a "projected BAU baseline"; and a "reconstructed BAU" baseline.[16] A projected baseline would set the baseline today, based on a fixed projection of an entity's BAU emissions for 2000 – 2007. An entity would know today exactly how many permits it would receive in 2008. In contrast, a reconstructed baseline would base emission entitlements on an assessment made in 2008 of what BAU emissions would have been for an entity over the period 2000 – 2007 had it not undertaken any EA. Thus, the actual determination of emission entitlements for 2008 – 2012 would not be made until 2008.

The proposal that currently appears to be gaining most favour in the NCCP is the reconstructed baseline approach.[17] This is a poor choice, for three reasons. First, it will be costly to establish an accounting structure for the purposes of "reconstructing" BAU emissions. Second, it creates uncertainty for entities about what their emission entitlements will be in 2008. Third, and most importantly, it creates the same moral hazard problem described earlier in the context of CEA. Under a reconstructed baseline system, an entity can effectively acquire additional emission entitlements by making investment and operational decisions that inflate its BAU emissions relative to its actual emissions. For example, if a firm expands capacity prior to 2008 but does so with a more GHG-efficient technology than it could have used, then it would be entitled to reconstruct its baseline on the basis of the higher emissions technology. Thus, the firm would receive valuable emission entitlements as a result of the investment. This additional private return could distort the investment decision. Indeed, the additional private return from

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[16] See Credit for Early Action Table (1999).

the investment could be high enough to turn an otherwise unprofitable project into a profitable one, and thereby generate GHG emissions that would not otherwise have been created.

The best resolution to this problem is to issue emission entitlements by auction. Failing that, a flat baseline or projected baseline approach should be used. The choice between those two approaches is essentially a matter of wealth distribution. In the benchmark scenario, the Kyoto emission rights in Canada have a market present value of about $207b. Auctioning would award that value to the state. A flat baseline approach would award it to past polluters; a projected baseline approach would award it to future polluters.

6. International Emissions Trading

If Canada is able to buy and sell emission reduction credits (ERCs) for the commitment period on an international market then it is no longer constrained to meet its Kyoto target solely on the basis of domestic emission reductions. Let $\bar{p}_2$ denote the equilibrium price of ERCs on the international market. (Canada will be a small player on the international market and its domestic actions will not influence this price). With the possibility of international ERC trading, the domestic planning problem is no longer the constrained optimization problem from section 3. The modified problem is:

$$(20)\quad \min_{\{x,y,e\}} \sum_{j=1}^{N}(x_{j1}+y_{j1})+\sum_{j=1}^{N}\gamma_j[b_{j1}-r_{j1}(y_{1j})-e_{j1}]^2-\delta_1\sum_{j=1}^{N}(b_{j1}-e_{j1})$$
$$+\beta\Big(\sum_{j=1}^{N}y_{j2}+\sum_{j=1}^{N}\gamma_j[b_{j2}-r_{j2}(x_{1j},y_{j1},y_{j2})-e_{j2}]^2-\delta_2\sum_{j=1}^{N}(b_{j2}-e_{j2})+\bar{p}_2[\sum_{j=1}^{N}e_{j2}-K_2]\Big)$$

Note that this formulation of the problem assumes that Canada buys only as many ERCs as it requires to meet its Kyoto obligation.[18] The solution to (20) is given by equations (21) – (25):

$$(21)\quad x_{i1}^T=\left[\frac{\beta\lambda_{i1}(\bar{p}_2+\delta_2)}{2}\right]^2$$

$$(22)\quad y_{i1}^T=\left[\frac{\alpha_{i1}\delta_1}{2}+\frac{\beta\theta_{i1}(\bar{p}_2+\delta_2)}{2}\right]^2$$

$$(23)\quad e_{i1}^T=b_{i1}-r_i(y_{i1}^T)-\frac{\delta_1}{2\gamma_i}$$

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[17] See Media Advisory (2000). Canadian companies are invited to register their early emission reductions at the Voluntary Challenge and Registry (http://www.vcr-mvr.ca/home_e.cfm).

(24) $$y_{i2}^{T} = \left[\frac{\alpha_{i2}(\bar{p}_2 + \delta_2)}{2} \right]^2$$

(25) $$e_{i2}^{T} = b_{i2} - r_{i2}(x_{i1}^{T}, y_{i1}^{T}, y_{i2}^{T}) - \frac{(\bar{p}_2 + \delta_2)}{2\gamma_i}$$

Note that co-benefits in period 2 (as measured by δ_2) now play a role in the optimal solution (in contrast to the purely domestic solution in section 3). In particular, the true opportunity cost for Canada of one ton of emissions in period 2 is the value of the ERC foregone (which could have been sold at $\bar{p}_2$ on the international market) *plus* the co-benefits foregone (valued at δ_2). Note that there are no foregone climate benefits because any change in Canada's emissions is directly offset by a change in emissions elsewhere (because the global Kyoto budget is fixed), and all that matters for the climate in Canada is total global emissions. In contrast, co-benefits are primarily a local air quality issue for which domestic emissions matter.

Simulation Results

Table 2 presents the optimal solution under international emissions trading (IET) when $\bar{p}_2 = 55$ (for the benchmark scenario).[19] At this price there are 439 Mt in ERCs purchased from the international market; this constitutes 16% of the Kyoto target. The lower MAC in period 2 means that substantially less EA is optimal under IET: early investment is only 28% of the optimal level without IET. The overall cost of Kyoto compliance is also much lower under IET: \$21.9b versus \$29.8b.[20]

Implementation with Domestic Emissions Trading

Accounting for co-benefits in period 2 means that the domestic price of emissions should in principle be higher than the world price for ERCs. The simplest way to achieve this would be to allow all permits to trade at the world price for ERCs, whether issued domestically or purchased internationally, and to impose a "permit submission fee" on any permit submitted against emissions produced domestically. This fee would be set equal to the value of marginal co-

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[18] In principle it could be worthwhile for a country to purchase ERCs on the international market and retire them (even while producing positive levels of domestic emissions). This could be optimal if the associated domestic climate benefits to that country exceed the price of the ERCs; such a scenario is highly unlikely for Canada.

[19] This price corresponds to the "Kyoto tight" scenario examined in Energy Research Group (2000).

[20] Note that MAC at the optimum under IET in Table 2 is \$60 while the international price of ERCs is only \$55; this difference reflects the value of co-benefits in period 2 (\$5 in the benchmark scenario).

benefits. The ET program described in section 5.6, combined with a permit submission fee in period 2, could then implement the optimal solution.

Credit for Early Action

The qualitative results for CEA derived in section 5 are not changed by the introduction of IET. However, the simulation results indicate that the quantitative distortion is of a smaller relative magnitude. Path 4 in Table 2 presents the solution under CEA with IET under the benchmark scenario. The distortion due to CEA is smaller under IET because the equilibrium permit price in period 2 is lower; this means that the effective subsidy to early emission reductions is also lower ($37 with IET versus $60 without IET). Nonetheless, there is still a 10% Kyoto cost inflation due to CEA, representing a $2.1b loss to the economy.

An Early Cap-and-Trade Program

Table 2 also presents the simulation results for two early cap-and-trade programs under IET (in the benchmark scenario). Recall that Path 5a represents a program with a permit price of $40 in period 1; Path 5b represents a program with a cap set equal to 1990 levels (on an average annual basis). These programs are relatively more distorting under IET: the cost inflations are 11% and 220% respectively under IET, versus 7% and 135% without IET. This exacerbation of the distortion arises because the compliance cost savings from EA are much lower under IET (because ERCs can be purchased at a relatively low price), but the restriction on period 1 emissions imposed by the early cap-and-trade program still forces entities to take significant EA. The exacerbation is most severe under Path 5b because the emission reductions required in period 1 are fixed under that policy. In fact, Canada becomes a net seller of international ERCs in that case.

7. OTHER ISSUES

The formal modelling in this paper has abstracted from a number of important policy issues, and these deserve at least some mention. First, there is no uncertainty in the model. In reality, there is no guarantee that the Kyoto Protocol will be ratified in its current form, and all EA must be tempered by that fact. Thus, it is important that EA policies be flexible enough to accommodate the associated uncertainty. The main policy approach advocated in this paper – trading in emission futures – would allow early CP permit prices to reflect the evolution of ratification uncertainty, and would also allow different entities to adopt different market positions depending on their expectations and risk exposure.

Second, the market-based return to EA in a well-functioning emission futures market may differ from its social return, quite apart from any consideration of environmental co-benefits. In particular, technology spillovers – at both the innovation and adoption stages of technological change – mean that EA may be undervalued in the market.[21] The best policy approach to this problem is to implement targeted measures that address these spillovers directly, through R&D subsidies, accelerated depreciation rules, and direct regulation where warranted (for example, in the case of strong network externalities). These policies should be viewed as supplemental to a well-designed ET program.

Third, the public sector itself is a significant producer of GHGs but its operations are often removed from market price signals. Thus, market-based incentives will not be enough to motivate appropriate EA in this sector. A higher degree of central planning with respect to EA will be needed in the public sector.

Fourth, the Kyoto Protocol currently specifies emission targets only for the first commitment period: 2008 – 2012. Unless there is a shift in scientific consensus on the causes of climate change then there is likely to be considerable pressure for a continuation, and possible tightening, of global GHG restrictions. In the formal model, accounting for an extension of the protocol in the determination of optimal EA can be approximated by reinterpreting "period 2" and reducing the discount rate between periods 1 and 2. However, the approximation is not exact. In particular, there is currently no provision in the Kyoto Protocol to allow trade in ERCs – domestically or internationally – across commitment periods. This is a serious shortcoming of the Protocol. In the same way that a focus on early emission reductions in Canada will distort investment decisions prior to 2008, the international focus on emission reductions for 2008 – 2012 will likely distort global investment decisions prior to 2012 relative to a longer term optimal plan.

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[21] See Parry and Toman (2000a) for a formal treatment of technology spillovers and early action.

8. CONCLUSION

This paper has argued that EA policies which focus on early actual emission reductions will tend to distort abatement investment decisions, and thereby inflate the national compliance cost of the Kyoto target. Compliance cost savings stem from well planned early action that may or may not yield early actual emission reductions. Thus, policies like CEA or an aggressive early cap-and-trade program have the potential to be highly distorting. The simulation results suggest that the associated welfare losses could be many billions of dollars. Early actual emission reductions are warranted primarily on the basis of the associated environmental co-benefits. This distinction between early co-benefits and compliance cost savings also means that a single policy instrument cannot correctly target both aspects of EA.

The policy approach advocated in this paper is the introduction of a very modest early cap-and-trade program, coupled with trading in emission futures whereby permits for emissions in 2008 – 2012 are issued gradually between now and 2008, and allowed to trade freely. Such a system would create the price signals required to motivate early action. All permits would be sold by auction. A supplementary set of policy measures is also needed to target technology spillovers and public sector emissions, but these should not be viewed as an alternative to a broad-based emissions trading program.

APPENDIX 1

Table A1: Sectoral Parameter Values – Benchmark Scenario

	BAU Emissions 2002 – 07 (Mt)	BAU Emissions 2008 – 12 (Mt)	Least-Cost Emissions 2008 – 12 (Mt)	α_1	θ_1	λ_1	γ	α_2
Electricity	688	646	257	1.50	1.65	1.50	0.89	1.50
Industry	1471	1279	1130	0.93	1.02	0.93	2.32	0.93
Residential & Agriculture	295	235	191	0.50	0.55	0.50	7.89	0.50
Transportation	1112	995	775	1.13	1.24	1.13	1.57	1.13
Other*	784	577	472	0.78	0.86	0.78	3.27	0.78
Total	**4350**	**3731**	**2825**					

* BAU emissions for 2008 – 2012 include emissions sequestered by sinks: – 10Mt per year for forestry and –5.8Mt per year for agriculture.

Sources: Analysis and Modeling Group (1999), Table C-25; Energy Research Group (2000), p.51.

Table A2: Scenarios

Scenario	Discount Rate	δ_1, δ_2	$\mathrm{A} = \frac{\alpha_1}{\alpha_2}$	$\Theta = \frac{\theta_1}{\alpha_2}$	$\Psi = \frac{\lambda_1}{\alpha_2}$	$\Gamma = \gamma\alpha_2^2$	MAC^*
1*	10	5	1	1.1	1	2	120
2	**5**	5	1	1.1	1	2	120
3	**12**	5	1	1.1	1	2	120
4	10	**0**	1	1.1	1	2	120
5	10	**10**	1	1.1	1	2	120
6	10	5	**0.5**	1.1	1	2	120
7	10	5	**1.5**	1.1	1	2	120
8	10	5	1	**1.5**	1	2	120
9	10	5	1	**2**	1	2	120
10	10	5	1	1.1	**0.5**	2	120
11	10	5	1	1.1	**1.5**	2	120
12	10	5	1	1.1	1	**1**	120
13	10	5	1	1.1	1	**3**	120
14	10	5	1	1.1	1	2	**80**
15	10	5	1	1.1	1	2	**140**

* Benchmark scenario

Table A3: Optimal Early Action under Alternative Scenarios

Scenario	Research & Planning ($b)	Capital Investment ($b)	Behavioural Abatement Costs ($b)	% of Kyoto Gap met by Early Action
1*	7.1	9.6	0.02	49
2	8.9	12.0	0.02	54
3	6.4	8.8	0.02	46
4	7.3	8.8	0	48
5	6.8	10.5	0.07	49
6	7.2	9.2	0.02	48
7	7.0	10.1	0.02	49
8	5.8	14.1	0.01	58
9	4.4	18.8	0.01	68
10	2.1	11.4	0.02	39
11	12.6	7.6	0.01	59
12	6.1	8.3	0.03	42
13	7.5	10.2	0.01	52
14	4.6	6.7	0.02	49
15	8.3	11.1	0.01	49

* Benchmark scenario

Table A4: Kyoto Compliance Cost under Alternative Paths as a Percentage of Least-Cost

Scenario	Path 2	Path 3	Path 4	Path 5a	Path 5b	Path 6
1*	203	100	117	107	235	121
2	232	100	118	106	213	124
3	194	100	116	107	245	120
4	191	100	117	108	227	116
5	219	101	116	106	246	129
6	202	100	111	104	459	110
7	205	100	124	112	146	144
8	253	100	112	105	272	117
9	335	100	108	103	358	112
10	169	100	118	108	199	126
11	261	100	115	105	295	116
12	177	100	122	108	222	124
13	217	100	115	106	243	120
14	211	100	116	116	240	125
15	202	100	117	105	234	121

* Benchmark scenario

APPENDIX 2

Proof of Proposition 1

Set $k_{i2}'(e_{i1}) = 0$ in (13) – (17). Then from (13), (14) and (16)

$$r_{i2}^T = \frac{\alpha_{i1}\theta_{i1}p_1}{2} + [\alpha_{i2}^2 + \beta(\lambda_{i1}^2 + \theta_{i1}^2)]\frac{p_2}{2} \tag{A1}$$

Then from (17):

$$e_{i2}^T = b_{i2} - \frac{\alpha_{i1}\theta_{i1}p_1}{2} - \left[\alpha_{i2}^2 + \beta(\lambda_{i1}^2 + \theta_{i1}^2) + \frac{1}{\gamma_i}\right]\frac{p_2}{2} \tag{A2}$$

Setting $\sum_{j=1}^{N} e_{j2}^T = K_2$ and solving for the equilibrium price yields

$$p_2^T = \frac{2\left[B_2 - K_2 - p_1\sum_{j=1}^{N}\left(\frac{\alpha_{j1}\theta_{j1}}{2}\right)\right]}{\sum_{j=1}^{N}[\alpha_{j2}^2 + \beta(\lambda_{j1}^2 + \theta_{j1}^2)] + \sum_{j=1}^{N}\left(\frac{1}{\gamma_j}\right)} \tag{A3}$$

Now set $p_1 = 0$ in (A3) and substitute into (13) and (14), also evaluated at $p_1 = 0$. Then comparing (13) and (14) with (7) and (8) proves parts (a) and (b). It then follows from part (b) that $r_{i1}(y_{i1}^T) < r_{i1}(y_{i1}^*)$, and so part (c) then follows directly from (15), evaluated at $p_1 = 0$. Part (d) is a direct corollary of parts (a) – (c). ν

Proof of Proposition 2

Set $p_1 = \delta_1$ in (A3) and the results follow directly from a comparison of (7) – (11) with (13) – (17), evaluated at $p_1 = \delta_1$, $k_{i2}'(e_{i1}) = 0$ and p_2^T from (A3). ν

Proof of Proposition 3

Set $p_1 = 0$ and $k'_{i2}(e_{i1}) = -\omega$ in (13) – (17). Let $\mu = \omega\left[\frac{\beta p_2}{\delta_1}\right]$. Then from (14) and (15),

$$y_{i1}^{T4} = \frac{\mu\alpha_{i1}\delta_1}{2} + \frac{\beta\theta_{i1}p_2^{T4}}{2} \tag{A4}$$

$$e_{i1}^{T4} = b_{i1} - r_{i1}(y_{i1}^{T4}) - \frac{\mu\delta_1}{2\gamma_i} \tag{A5}$$

where the “T4” superscript denotes the solution in the CEA equilibrium (path 4 in the simulation). Define

$$p_2^* = \frac{2\left[B_2 - K_2 - \delta_1\sum_{j=1}^{N}\left(\frac{\alpha_{j1}\theta_{j1}}{2}\right)\right]}{\sum_{j=1}^{N}[\alpha_{j2}^2 + \beta(\lambda_{j1}^2 + \theta_{j1}^2)] + \sum_{j=1}^{N}\left(\frac{1}{\gamma_j}\right)} \tag{A6}$$

Now suppose $\mu > 1$; that is, $\beta\omega p_2 > \delta_1$. Then it follows from a comparison of (8) with (A4) evaluated at (A6) that $y_{i1}^{T4}(p_2^*) > y_{i1}^* \;\; \forall i$. In addition, it follows from (7) and (13) that $x_{i1}^{T4}(p_2^*) = x_{i1}^* \;\; \forall i$, and from (10) and (16) that $y_{i2}^{T4}(p_2^*) = y_{i2}^* \;\; \forall i$. Thus, $r_{i2}^{T4}(p_2^*) > r_{i2}^* \;\; \forall i$. It then follows from (17) that $\sum_{j=1}^{N} e_{j2}^{T4}(p_2^*) < K_2$ since $\sum_{j=1}^{N} e_{j2}^* = K_2$. Therefore, since $\sum_{j=1}^{N} e_{j2}^{T4}(p_2^{T4}) = K_2$ and $e_{i2}^{T4}(p_2)$ is decreasing in p_2, $p_2^{T4} < p_2^*$. Results (a) and (b) then follow from a comparison of (13) and (A4) with (7) and (8). Since $y_{i1}^{T4} > y_{i1}^*$, it follows that $r_{i1}(y_{i1}^{T4}) > r_{i1}^*$, and so result (c) follows directly from (9) and (A5). Part (d) is a direct corollary of parts (a) – (c). Conversely, if $\mu < 1$ (that is, $\beta\omega p_2 < \delta_1$), then $p_2^{T4} > p_2^*$ and the converse relationships hold.

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Proof of Proposition 4

Set $k'_{i2}(e_{i1}) = 0$ in (13) – (17). Then from (14) and (15),

$$\text{(A7)} \qquad y_{i1}^{T5} = \frac{\alpha_{i1} p_1^{T5}}{2} + \frac{\beta\theta_{i1} p_2^{T5}}{2}$$

$$\text{(A8)} \qquad e_{i1}^{T5} = b_{i1} - r_{i1}(y_{i1}^{T5}) - \frac{p_1^{T5}}{2\gamma_i}$$

where the "T5" superscript denotes the solution in the early cap-and-trade equilibrium (path 5 in the simulation). Now suppose $p_1^{T5} > \delta_1$. Then it follows from a comparison of (8) with (A7) evaluated at (A6) that $y_{i1}^{T5}(p_2^*) > y_{i1}^* \ \forall i$. Applying the same logic used in the proof of proposition 3, it follows that $p_2^{T5} < p_2^*$. Results (a) and (b) then follow from a comparison of (13) and (A7) with (7) and (8). Since $y_{i1}^{T5} > y_{i1}^*$, it follows that $r_{i1}(y_{i1}^{T5}) > r_{i1}^*$, and so result (c) follows directly from (9) and (A8). Part (d) is a direct corollary of parts (a) – (c). Conversely, if $p_1^{T5} = \delta_1$ then $p_2^{T5} = p_2^*$, and the equilibrium implements the optimal solution. ν

Proof of Proposition 5.

Set $p_1 = 0$ in (13) – (17). Then from (14) and (15),

$$\text{(A9)} \qquad y_{i1}^{T6} = \frac{\beta\theta_{i1} p_2^{T6}}{2} - \frac{\beta\alpha_{i1} p_2^{T6} k'_{i2}}{2}$$

and

$$\text{(A10)} \qquad e_{i1}^{T6} = b_{i1} - r_{i1}(y_{i1}^{T6}) + \frac{\beta p_2^{T6} k'_{i2}}{2\gamma_i}$$

where the "T6" superscript denotes the solution in the no BLP equilibrium (path 6 in the simulation). Now suppose $\delta_1 = 0$. Then it follows from a comparison of (8) with (A9) evaluated at (A6) that $y_{i1}^{T6}(p_2^*) < y_{i1}^* \ \forall i$ since $k'_{i2} > 0$. Applying the same logic used in the proof of proposition 3, it follows that $p_2^{T6} > p_2^*$. It then follows from a comparison of (13) with (7) that $x_{i1}^{T6} > x_{i1}^*$. This proves part (a). Summing across *j* in (17) and noting that $\sum_{j=1}^{N} e_{j2}^{T6}(p_2^{T6}) = K_2$ yields

$$\text{(A11)} \qquad \sum_{j=1}^{N} r_{j2}^{T6} = B_2 - K_2 - p_2^{T6} \sum_{j=1}^{N} \left(\frac{1}{\gamma_j} \right)$$

Since $p_2^{T6} > p_2^*$, it follows that $\sum_{j=1}^N r_{j2}^{T6} < \sum_{j=1}^N r_{j2}^*$. In addition, it follows from a comparison of (16) and (10) that $y_{i2}^{T6} > y_{i2}^*$, since $p_2^{T6} > p_2^*$, and from part (a) that $x_{i1}^{T6} > x_{i1}^*$. Thus, it follows that $\sum_{j=1}^N \theta_{i1}[y_{j1}^{T6}]^{1/2} < \sum_{j=1}^N \theta_{i1}[y_{j1}^*]^{1/2}$. This proves part (b). Part (c) follows directly from a comparison of (15) and (9), since $p_2^{T6} > p_2^*$, $k_{i2}' > 0$ and $p_1 = \delta_1 = 0$. Part (d) is a direct corollary of parts (a) – (c). ν

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TEXT TABLES

Table 1: Optimal Early Action Solution (Path 1) vs Alternative Policy Paths

	Path 1	Path 2	Path 3	Path 4	Path 5a	Path 5b	Path 6
Research & Planning ($b)	7.1		7.3	4.8	5.6	1.7	10.2
Capital Investment ($b)	9.6		8.8	21.0	16.4	53.5	2.0
Behavioural Abatement ($b)*	0.02			2.4	1.1	17.3	2.2
Effective Abatement Subsidy ($)				60			
Permit Price in Period 1 ($)					40	162	
Emissions in Period 1 (Mt)	4118	4350	4135	3938	4004	3606	4322
Credits Awarded (Mt)				412			
Emission Reductions in Period 2 due to EA (relative to BAU) (Mt)	441		433	524	494	678	346
Permit Price (or MAC) in Period 2 ($)	118	230	120	97	105	58	142
Present Value of Co-Benefits ($b)	4.0	2.8	3.9	4.9	4.5	6.5	3.0
Kyoto Compliance Cost ($b)	**29.8**	**60.7**	**29.9**	**34.8**	**31.8**	**70.1**	**36.2**
Cost as a % of Least-Cost	100	203	100.3	117	107	235	121

* For Path 6 this represents the cost of *negative* behavioural abatement.

Table 2: Early Action with International Emissions Trading

	Path 1 without IET	Path 1 with IET	Path 4 with IET	Path 5a with IET	Path 5b with IET
Research & Planning ($b)	7.1	1.8	1.8	1.8	1.8
Capital Investment ($b)	9.6	2.8	8.1	8.6	53.8
Behavioural Abatement Costs ($b)	0.02	0.02	0.9	1.1	17.1
Effective Abatement Subsidy ($)			37		
Permit Price in Period 1 ($)				40	161
Emissions in Period 1 (Mt)	4118	4223	4095	4085	3606
Credits Awarded (Mt)			255		
Emission Reductions in Period 2 due to EA (relative to BAU) (Mt)	441	231	324	332	683
Emissions in Period 2 (Mt)	2825	3264	3170	3162	2811
International ERC Purchases (Mt)		439	345	337	– 14
Permit Price (or MAC) in Period 2 ($)	118	60	60	60	60
Present Value of Co-Benefits ($b)	4.0	2.1	3.0	3.1	6.6
Kyoto Compliance Cost ($b)*	**29.8**	**21.9**	**24.0**	**24.3**	**70.1**
Cost as a % of Least-Cost under IET	136	100	110	111	320

* Includes the present value of ERC purchases