Early Emissions Reduction Programs: An Application to CO_2 Policy

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Abstract

In the wake of the December 1997 Kyoto Protocol, which, if implemented, would oblige the United States and other industrialized countries to reduce greenhouse gases (GHGs) by 2008–2012, a number of proposals have been offered to increase the incentives for reducing emissions over the nearer term. The existence of an interim period between setting and implementing environmental goals is ubiquitous in environmental policymaking. The existence of this interim period gives rise to several potential rationales for early emissions reductions. In this paper we use a series of simple models and numerical illustrations to analyze some aspects of the performance of early emissions reduction programs in the case of GHGs.

We show that there is a compelling economic case for allowing early GHGs reduction credits if countries (not just individual firms) could bank early credits to offset future emissions. The annualized cost savings to the United States from spreading out abatement over time could easily amount to several billion dollars. But without the aggregate banking provision, such credits could easily generate an excessive amount of abatement and produce net economic losses. We analyze a number of other issues that affect the economic efficiency of early reduction credits, including asymmetric information, learning-by-doing (LBD), and fiscal impacts. We also compare the performance of an early reduction credits program with that of an early cap-and-trade program. This latter approach, *if* properly scaled, can avoid many of the problems associated with early reduction credits.

Key Words: early reduction credits, carbon emissions, welfare impacts, permit banking, cap-and-trade

JEL Classification Numbers: Q28, H23, Q48

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1. Introduction

The Kyoto Protocol, negotiated at the December 1997 Third Conference of the Parties to the UN Framework Convention on Climate Change in Kyoto, Japan would—if implemented—require industrialized countries pledged to reduce their average annual emissions of carbon dioxide and other heat-trapping greenhouse gases (GHGs) by around 5%, relative to 1990 emissions levels, over the period 2008-2012. The idea of negotiating environmental goals but implementing them in the future is not unique to the issue of GHGs. It was also a part of the Montreal Protocol for reducing and eventually phasing out emissions of ozone-depleting substances, and it is commonplace in domestic environmental regulation.

The lag between the establishment of an environmental target and its implementation often gives rise to debate about the prospects for initiating emissions reductions earlier. In the case of GHGs, some observers have called for some kind of early emissions reduction program to control GHGs in the United States before 2008. There are several possible rationales for an early reductions program. Some advocates favor such a program because they question whether short-term incentives to prepare for expected future constraints will be adequate without one. But even if one accepts (as we do) the basic efficacy of markets in preparing for future constraints given clear policy signals, one can identify three possible efficiency-enhancing rationales for an early reductions program.

First, the program might produce direct economic welfare gains, depending on the environmental benefits and costs from emissions limitations over the precommitment period. Second, the program might lower the future costs of meeting the environmental target by encouraging firms to develop less emissions-intensive production methods earlier. Third, early emissions reductions could allow for cost-smoothing opportunities over time. In particular, if

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countries could bank credits for low-cost early emissions reductions, then significant cost-savings might be obtained by allowing firms to arbitrage marginal abatement costs over time.[1]

Most proposals for early action offered in the United States advocate that various GHGs-emitting firms be given credits, called *early emissions reduction credits*, for qualified emissions reductions they undertake prior to 2008. Under this scheme, for each unit of emissions reduced before 2008, recipients of a credit for early action would be entitled to one free permit from the total pot of future permits for each unit of voluntary emissions reductions in the intervening years. This presumes use of some kind of formal emissions trading system after 2008. The remaining stock of permits would either be allocated gratis according to some formula (e.g., grandfathered) or auctioned off.[2]

One criticism of early reduction credits involves the difficulty of monitoring whether firms' claims about their emissions reduction are genuine. In the absence of early reduction credits, firms may have reduced emissions for other reasons; for example, a firm may adopt an energy-saving technology to reduce its production costs. This gives rise to an adverse selection problem, because regulators may be unable to distinguish between firms whose emissions fall due to genuine abatement activity and firms whose emissions fall as a by-product of a privately optimal decision (e.g., Repetto 1998). Moreover, the incentives for voluntary early action depend on the expected future permit price, which is very uncertain, for economic reasons and because of the possibility that the Kyoto Protocol ultimately will not be implemented. To avoid these problems, Kopp et al. (1999) have advocated introducing a mandatory early cap-and-trade emissions program instead of early emissions reduction credits.

In this paper we examine the case of early GHG reductions. We use a series of simple models and numerical illustrations to analyze some aspects of the performance of early reduction credits and to compare them with an early cap-and-trade program. In Section 2 we first

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[1] This last rationale would not arise if regulatory targets were set to minimize the present value of compliance costs over time, but there is no reason to presume automatically that this is the case. A further rationale, which we do not analyze here, is the benefit from experimenting with regulatory institutions for future GHGs control. In the United States, implementation of the SO_2 trading program in 1995 was preceded by various pilot activities to test out the regulatory institutions. Supporters of early action to reduce GHGs seek a similar opportunity for regulatory experimentation.

[2] For details on the structuring of early reduction programs, see Repetto (1998) and GAO (1998).

introduce a simple two-period model describing abatement costs and incentives in the precommitment period and the commitment period, respectively. In this initial model, early reduction credits do not affect the outcome in the commitment period, because this is determined by the binding quota. We show that the net benefit of early reduction credits is highly uncertain. Under a high environmental benefit/moderate abatement cost scenario early reduction credits can produce an annualized net benefits of several billion dollars or more. But abatement could easily be excessive under a more moderate benefit/high cost scenario, in which case early reduction credits could produce net losses in excess of several billion dollars per annum. We also examine the potential gains from allowing the banking of early reduction credits under the Kyoto Protocol. In this case, early reduction credits spread abatement out over time, rather than increasing the overall amount of abatement. The resulting cost savings could easily amount to several billion dollars per annum.

In Section 3 we develop a simple model of adverse selection in which low-cost firms, by posing as high-cost firms, attempt to claim credits for emissions reductions they would have done anyway. In cases where such “anyway” reductions are substantial, true abatement activity at low-cost firms is significantly lower in the presence of asymmetric information, and inefficiency arises because marginal abatement costs differ among firms.

In Section 4 we discuss how early reduction credits affect the capacity of learning-by-doing (LBD) to reduce abatement costs in the commitment period. In this model there are incentives for LBD even in the absence of early reduction credits, although these incentives may fall short of the social optimum. We find that the future benefits from LBD may offset a significant portion of the economic costs of early reduction credits in the precommitment period. However, early reduction credits can easily induce too much LBD relative to the socially optimal amount.

In Section 5 we emphasize a potentially significant drawback of early reduction credits that has not been previously recognized. In the event that some or all future emissions permits would be auctioned rather than allocated gratis to firms, early reduction credits would crowd out some of the potential revenues from permit sales. Consequently, either the rate of distortionary taxes must be higher or public spending lower. Our back-of-the-envelope calculation suggests that this effect could raise costs under early reduction credits programs by about 75%. Section 6 briefly compares the performance of programs with early emissions credits to an early cap-and-

trade program. The main point here is that a cap-and-trade program with an appropriate total emissions targets can avoid many of the problems with early reduction credits that our analysis highlights.

We sum up our findings in Section 7. We note that there would be a very compelling case on the grounds of cost-effectiveness for early reduction credits programs, or early cap-and-trade programs, if the Kyoto Protocol were amended to allow countries to use early reduction credits to offset additional emissions in the commitment period. Without this banking provision, however, the economic case for early reduction credits depends on the benefits and costs and also the extent of additional (early) abatement. A larger-scale early reduction credits program seems unlikely to generate environmental or learning-by-doing benefits large enough to justify the abatement costs. A smaller-scale cap-and-trade program is more likely to generate net benefits as well as outperforming a comparably scaled early reduction credits system.

2. A Basic Model of Early Reductions

This section lays out the basic model and presents some calculations of the net benefits of early emissions reduction credits. We consider cases in which the banking of credits by countries is precluded and permitted.

(i) Model Assumptions

Consider a two-period model in which a large number of homogeneous firms produce carbon emissions as a by-product of economic activity (Section 3 allows for heterogeneous firms).[3] Firms face the following quadratic cost function for reducing emissions in a period:

$$(2.1) \qquad C^i(M_i - e_i) = \frac{c_i}{2}(M_i - e_i)^2$$

where e_i is the firm's emissions level, c_i is a positive parameter and i = 1 or 2 denotes time periods. In this simple model we ignore fixed costs of abatement activity. M_i denotes the business-as-usual (BAU) level of emissions per firm, the emissions level associated with the

[3] For simplicity, we restrict our discussion to carbon emissions—the primary greenhouse gas—rather than all greenhouse gases combined.

profit-maximizing energy use in the absence of carbon policy.[4] $M_i - e_i$ is therefore emissions abatement. The marginal cost of emissions abatement is given by

$$(2.2) \quad -\frac{dC^i}{de_i} = c_i(M_i - e_i)$$

This is positive when $e_i < M_i$ and the marginal cost curve comes out of the origin.

Suppose that the government has signed an international agreement to limit carbon emissions (i.e., average emissions per firm) to $\overline{Q} < M_2$ in the second or commitment period, but there is no international obligation to control first (precommitment) period emissions. The government proposes to control period two emissions by implementing a tradable emissions permit program, and, for the moment, we assume that the permits will be grandfathered to existing firms. We denote the market price of permits in period two by P_2, and we assume that P_2 is known with certainty (this is relaxed later). The private and social discount factors relating the two periods are assumed to be the same and equal to β.

With or without early reductions programs, the commitment period equilibrium will be characterized by

$$(2.3) \quad \tilde{e}_2 = \overline{Q}, \quad P_2 = c_2(M_2 - \tilde{e}_2)$$

In this initial model, early action does not alter the commitment period emissions quota or cost function. In the second period equilibrium, marginal abatement cost equals the price of a permit at an emissions level that satisfies the quota. Early emissions credits, if offered in the first period, do not affect this equilibrium; they serve only to redistribute the trading rents earned by different firms.[5]

Suppose that the government offers early reduction credits in the first period and, for now, assume that there is no limit on the available amount of credits. Assume further that these credits are non-bankable at the national level, in the sense that they do not augment the commitment period emissions constraint. (Individual firms do hold the credits to exchange for

[4] In a more elaborate model, the M_i are endogenous and M_2 reflects the anticipation of future regulation. This is illustrated in Sections 3 and 4 below.

[5] Of course, rent redistribution effectively occurs only when firms are heterogeneous (see below).

permits once the commitment period starts.)[6] Firms seeking early credits will solve the following maximization problem:

$$\text{(2.4)} \quad \max \quad \left\{ -C^1(M_1 - e_1) + \beta[P_2(\overline{Q} - e_2 + M_1 - e_1) - C^2(M_2 - e_2)] \right\}$$

$\overline{Q} - e_2$ is the amount of permits the firm will have at its disposal in period two from grandfathering, net of the permits required to cover period two emissions, and $M_1 - e_1$ is additional permits because of early reduction credits. The term in square brackets reflects the earnings from permit sales (or net costs from permit purchases) net of abatement costs in the commitment period. The firm maximizes the discounted value of this period two return, minus period one abatement costs. Second period emissions satisfy (2.3) so that the permit price in (2.4) is the same as if there were no early reduction credits.

Using the first order conditions from (2.4), and (2.2), early reductions satisfy

$$\text{(2.5)} \quad \beta P_2 = c_1(M_1 - \tilde{e}_1)$$

That is, the marginal cost of abatement in period one equals the (expected) discounted permit price.[7]

(ii) Numerical Results: Environmental Benefits and Costs of Early Reduction Credits

To obtain some numerical results, we calibrate the cost model as follows. Based on figures from the Energy Information Administration (U.S. EIA 1999, p. 89), carbon emissions in the United States in 1999 were 1,552 million tons, and BAU emissions in 2010 (M_2) are projected to be 1,787 million tons. Our two periods effectively represent blocks of time, which we assume are the two five-year periods 2003–2007 and 2008–2012. Taking a linear extrapolation, projected BAU emissions in 2005 would be 1,680 million tons, which we use as

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[6] To keep things simple, we assume that all firms in the economy that produce emissions will be covered by future permits and that all firms are eligible for credits. Incomplete coverage would introduce a separate source of inefficiency.

[7] Early emissions reduction credits effectively subsidize emissions abatement in period one at rate βP_2. In theory, an efficiency drawback of abatement subsidies is that they can encourage the entry of new polluting firms into the industry by raising firm profitability (Baumol and Oates 1988). This is not a relevant consideration, though, if we assume that early reduction credits are only granted to firms that were in the industry at the start of the first period.

our value for M_1.[8] If implemented, the Kyoto Protocol would restrict emissions to 93% of 1990 levels, which amounts to 1,251 million tons ($\overline{Q}$). In other words, the Protocol, if implemented, would reduce emissions by about 30% below BAU levels in 2010, or 536 million tons. For simplicity, we make the assumption that the marginal cost of a given percentage reduction in emissions is the same over time, therefore $c_1 = c_2 M_2 / M_1$.[9] Note that β is a compound discount factor; in our context, $\beta = (1+\rho)^{-N}$, where $N = 5$ in relation to the two time intervals specified above and ρ is the annual discount rate. Assuming an annual social discount rate of 5% implies a value for β of 0.78.[10]

From (2.3) and (2.5):

$$(2.6) \qquad M_1 - \tilde{e}_1 = \frac{\beta c_2 (M_2 - \overline{Q})}{c_1}$$

Using (2.6) and the above figures, our simple model predicts that early reduction credits would reduce emissions by 393 million tons per annum, or 23%, in the precommitment period.

There is considerable uncertainty over the future costs to the United States of complying with the Kyoto emissions targets described above. In order to complete the calibration of the cost model, we use two plausible assumptions about the future equilibrium shadow price of carbon emissions (in current dollars) if U.S. emissions were 30% below BAU levels in 2010. The lower abatement cost scenario derives from a \$50/ton shadow price, while the higher abatement cost scenario derives from a \$150/ton shadow price.[11]

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[8] Thus, we assume annual average figures for each time period are equal to those for the central year of the time block.

[9] In other words, we assume that the marginal cost schedule in period two is an outward rotation of the period one schedule to account for the larger scale of BAU emissions in period two. We take a neutral position on whether there are economies of scale in emissions reduction as a result of economic growth. We also abstract here for possible future cost decreases due to anticipation of regulation.

[10] This is the discount rate assumed by Nordhaus (1994) and a number of other analysts. Given the shorter-term nature of our cost analyses, different choices will not greatly affect our results.

[11] See the discussion in IWG (1997) and CEA (1998); Weyant and Hill (1999) provided a broader review of the current state of the abatement cost literature. The costs are lower in models that assume a greater degree of substitution between fossil fuels and other inputs. In addition, costs are lower the greater the extent of international permit trading assumed (no trading versus trading with Annex 1 countries versus trading with all countries). With trading, U.S. abatement in period two would be less than the 536 million tons assumed above; however, the difference is made up by paying for additional emissions at the permit price. In this case the marginal abatement cost

Since period two marginal abatement costs ($c_2 \times 536$ million tons) equal the permit price in the commitment period, the \$50/ton and \$150/ton shadow prices imply values for c_2 of \$0.093/million tons and \$0.28/million tons, respectively. Using $c_1 = c_2 M_2 / M_1$, c_1 is \$0.099/million tons or \$0.298/million tons. This in turn implies an annualized cost of the 393 million tons of abatement in period one of \$7.7 billion or \$23.0 billion—a substantial amount in either case.

To consider net benefits (i.e., environmental benefits less abatement costs) suppose that D represents the constant marginal damage of increased carbon emissions today/marginal benefits from abatement.[12] Using (2.5), the socially optimal amount of early abatement satisfies $\beta P_2 = D$. Estimates of environmental benefits are subject to much uncertainty and controversy. Based on our reading of the literature, benefits per ton could be anywhere between \$0 and \$100 or more. We adopt a value of \$25/ton.[13] Note that an early abatement of 393 million tons maximizes net benefits in this analysis if environmental benefits are \$39/ton in the lower abatement cost case and \$117/ton in the higher abatement cost scenario. In other words, an early reduction credits program will generate excessive abatement in this simple model, unless environmental benefits are relatively large.

In Table 1 we show calculations of the net benefits of the early emissions reduction of 393 million tons induced with an early reduction credits program, using different scenarios for

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curve is upward sloping until the marginal cost reaches the permit price, and flat thereafter. It still lies between the marginal cost curves in our low and high cost scenarios, which are always upward sloping.

12 In practice, carbon emissions (and particularly those of the United States, rather than global emissions) from 2003–2012 will be very small relative to future atmospheric concentrations of carbon dioxide. This means that, even if marginal environmental damages increase with higher atmospheric concentrations, it is probably reasonable to take the damages per ton from 2003–2012 US emissions as constant. See Pizer (1997, 1999) for more discussion of this.

13 In 1990 dollars Fankhauser (1994) obtained \$20/ton, which amounts to about \$25/ton in current dollars. Nordhaus (1994, 1999) used somewhat lower values. The scenario justifying these values reflects the notion that continued accumulation of greenhouse gases will not produce extreme changes in climate over the next century and that most economic activities and values are not exceptionally sensitive to intermediate climate change. In addition, discounting over long periods of time substantially reduces the benefit estimates, which are present values. Much higher abatement benefit estimates arise if there are greater physical impacts of climate change, sensitivity of economic activities and values to such change (as could be the case in developing countries), or lower discount rates. Roughgarden and Schneider (1999) and Tol (1999) addressed some of these issues in arguing that there is a long upper tail of possible damage estimates. The more modest benefit figures also do not reflect the possibility of shorter-term “ancillary benefits” from reduced conventional pollutants (Burtraw et al. 1999).

Table 1. Net Benefits from (Unlimited) Early Reduction Credits

($billion per annum)

Permit price in commitment period	*Marginal environmental benefits ($/ton)* 5	25	50	100
50	–5.7	2.2	12.0	31.7
150	–21.0	–13.2	–3.4	16.3

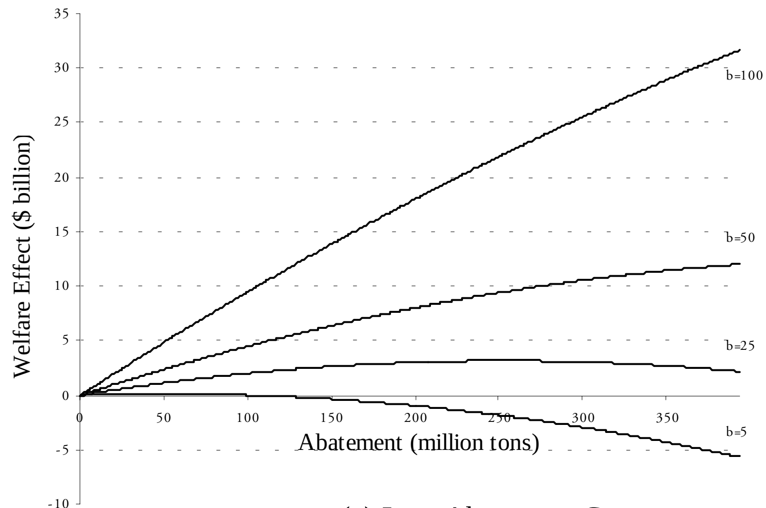
environmental benefits and costs.[14] In the $50/ton abatement cost scenario, early reduction credits produce a welfare gain of $12.0 to $32.7 billion per annum, if environmental benefits are $50 to $100 per ton. But in the lower $25/ton benefit scenario, early reduction credits produce a smaller net benefit of $2.2 billion. In the higher $150/ton abatement cost scenario, early reduction credits produce net losses, possibly amounting to over $10 billion per annum, when environmental benefits are $50/ton or less.

These calculations suggest that an early reduction credits program could induce only modest net benefits at best, and large net losses at worst, unless environmental benefits are relatively large. The problem is that the high shadow price to meet the later commitment for emissions reduction implies excessive early reductions. In other words, the future emissions control target is too stringent, and the potential economic loss from a voluntary early emissions reduction program is a corollary of that.

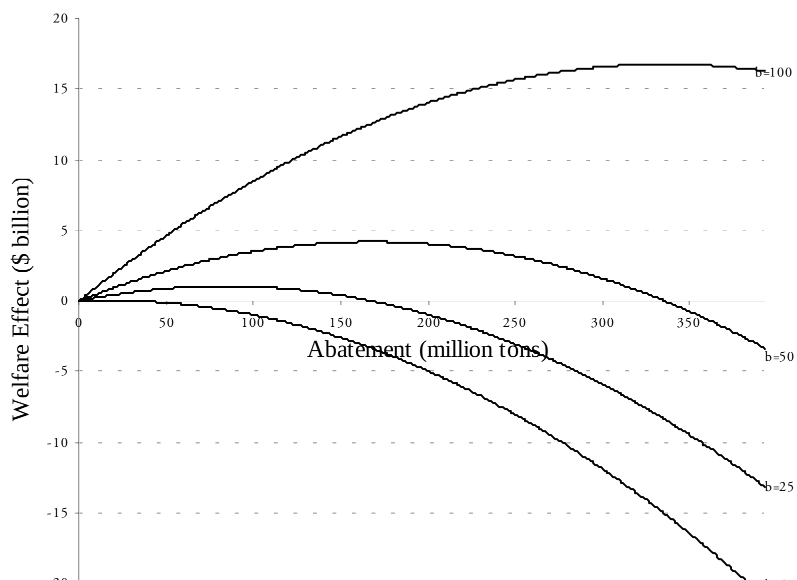
In Figure 1 we illustrate the net benefits of early emissions reduction spanning the entire range of abatement from 0 to 393 million tons. The upper and lower panels correspond to our lower and higher abatement cost scenarios, respectively, and the individual curves show the net benefits for marginal environmental benefits of $5, $25, $50, and $100 per ton. We see that in the lower abatement cost scenario, assuming a benefit estimate of $25 per ton, the maximum net

[14] Note that, even though the assumed future permit price in the higher-cost scenario is three times as high as in the low-cost scenario, this does not imply more abatement in the first period, since period one (marginal) costs are also three times as high.

Figure 1. Net Benefits from Early Abatement



(a) Low Abatement Costs



(b) High Abatement Costs

benefit is $3.2 billion when abatement is 250 million tons. But in the higher abatement cost scenario, assuming a marginal environmental benefit of $25 per ton, the maximum net benefit

falls to $1 billion at an abatement level of 85 million tons. In these cases, then, the optimal abatement is 22% to 64% of the unlimited abatement level (393 million tons). Figure 1 underscores the point that early reduction credits could easily induce an excessive amount of abatement.

(iii) Credit Limits and Uncertainty over the Future Permit Price.

In practice though, abatement is likely to be somewhat lower than the 393 million tons which lies behind the figures in Table 1. Some proposals for early reduction credits include limits on the total amount of credits that could be given out. If binding, this limit would obviously reduce the amount of early abatement. Similarly, doubt about whether future targets actually will be implemented, feeds back on the incentives created by early reduction credits.[15] The same kind of negative incentive effect would result if holders of early reduction credits have doubts about the ability to redeem the credits in the future.

These impacts on an early reduction credits program can be analyzed by supposing that firms predict that the emissions quota in the commitment period will be implemented with probability π. The expected permit price in period two is now πP, and the marginal private benefit from period one abatement falls from βP to $\pi\beta P$. Through the appropriate choice of π, one can also use this approach to model limits on the early reduction credits made available.

Suppose then that π=0.5, so that uncertainty or credit limits imply an abatement level of 197 million tons rather than 393 million tons. The reduced abatement implies that net benefits are higher, or net losses are sharply reduced, when environmental benefits are below $25/ton (given low abatement cost) or $50/ton (given high abatement cost) (see Figure 1). Another way of illustrating the point is that, if benefits are $25/ton, optimal period one abatement is induced if π is 0.64 (low abatement cost) or 0.22 (high abatement cost).[16]

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[15] For example, it is uncertain whether the Kyoto Protocol will ever be ratified by the U.S. Senate.

[16] This does *not* mean that the optimal response to regulatory uncertainty is to have a larger-scale early emissions reduction program. A better approach is to find ways to reduce or circumvent the uncertainty while designing a regulatory program that limits excessive early abatement. We return to this point in Section 6 below.

(iv) Nationally Bankable Early Credits

The Kyoto Protocol does not allow countries to bank credits for early abatement to offset emissions during the commitment period that are in excess of the quota. But it would make sense from the standpoint of overall cost-minimization to allow such banking, regardless of the Protocol's fate, so that all regulated firms or other actors could arbitrage (marginal) abatement costs over time for a given total amount of emissions released.[17] We next present some rough estimates of the economic gains from early reduction credits with aggregate banking versus no credits at all.

With bankable credits the sum of period one and two emissions must now satisfy[18]

(2.7) $e_1 + e_2 = M_1 + \overline{Q}$

It is straightforward to show that

(2.8) $c_1(M_1 - \hat{e}_1) = \beta c_2(M_2 - \hat{e}_2)$

That is, firms would equate marginal abatement costs in period one with the discounted marginal abatement cost in period two.

The discounted sum of abatement costs with bankable credits is given by:

(2.9) $C_b = \frac{c_1}{2}(M_1 - \hat{e}_1)^2 + \frac{\beta c_2}{2}(M_2 - \hat{e}_2)^2$

where, solving (2.7) and (2.8),

(2.10) $\hat{e}_1 = \frac{(1+\beta c_2/c_1)M_1 - \beta(M_2 - \overline{Q})c_2/c_1}{1+\beta c_2/c_1}$; $\hat{e}_2 = \frac{\overline{Q} + \beta M_2 c_2/c_1}{1+\beta c_2/c_1}$

[17] This argument is a short-term complement to that made by Manne and Richels (1997) about the ability to achieve long-term GHGs target levels at lower cost with intertemporal optimized targets. Leiby and Rubin (2000) argue that over the longer term such flexibility can have adverse welfare consequences by aggravating climate change damages.

[18] In practice, CO_2 emissions in the atmosphere naturally diminish at about 1% per annum. Adjusting credits to take this into account would have only a minor impact on our calculations, given their relatively short-term focus.

In the absence of any credits, all abatement would occur in the second period ($e_1 = M_1, e_2 = \overline{Q}$), and discounted abatement costs would be

$$(2.11) \quad C_n = \frac{\beta c_2}{2}(M_2 - \overline{Q})^2$$

Using these formulas, Table 2 shows calculations of C_n, C_b and $C_n - C_b$, assuming the above figures for M_1, M_2 and $\overline{Q}$, and the same range of abatement cost parameters. With no credits, emissions abatement is 536 million tons in the second period, and annualized (discounted) abatement costs then are $10.4 to $31.3 billion. With bankable credits, emissions abatement is 227 million tons in the first period and 309 million tons in the second. This spreading out of abatement produces very substantial cost savings, depending on the marginal cost of abatement (in the absence of banking) in the commitment. Marginal costs of $50, $100, and $150 per ton imply savings of $4.3, $8.4 or $12.7 billion per annum, respectively.[19]

Table 2. Cost Savings from Bankable Reduction Credits

($billion per annum)

	permit price in commitment period without banking ($/ton)		
	50	100	150
Cost without credits	10.4	20.9	31.4
Cost with bankable credits	6.2	12.5	18.7
Cost saving	4.2	8.4	12.7

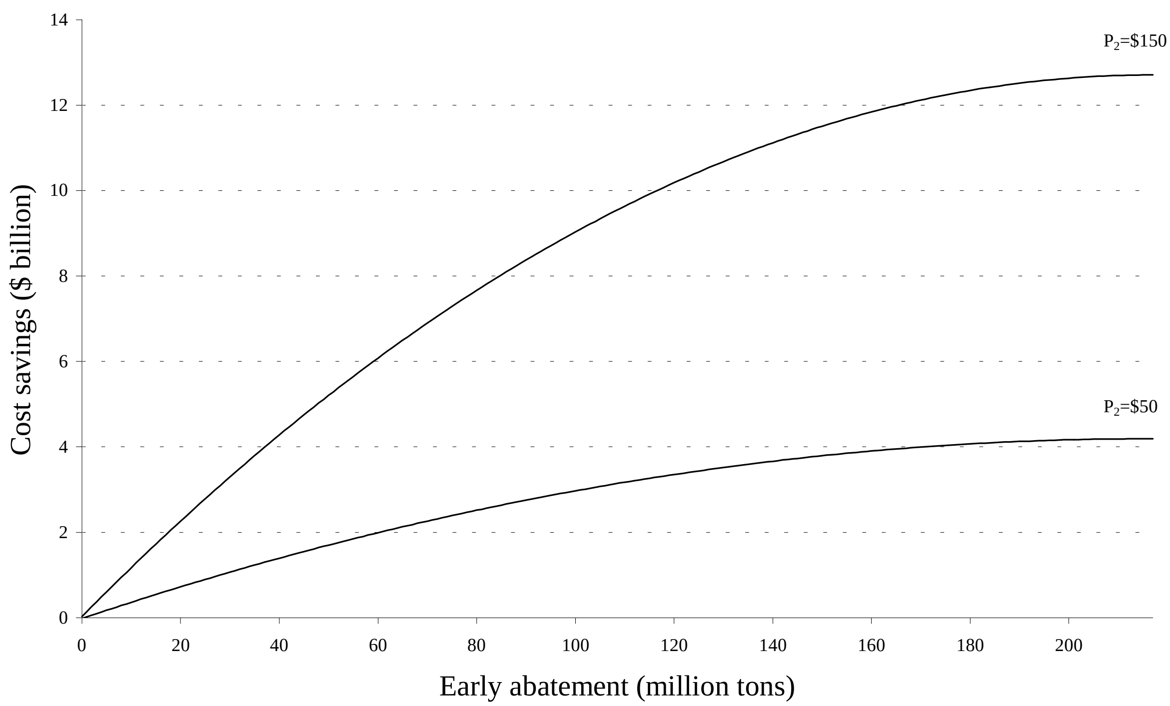
[19] Our assumptions about the marginal cost schedules in periods one and two may bias downward to the cost of early reduction and bias upward the arbitrage value of bankable early reduction credits. The assumption that marginal cost in period one goes through the origin seems reasonable, since in the pre-commitment period there has been no history of deliberate carbon abatement activity. However, early reduction in the pre-commitment period could raise the vertical intercept of the period two marginal cost schedule by depleting some one-shot opportunities for low-cost abatement. This possibility would be interesting to explore in further research with more complex empirical modeling.

Now suppose that emissions in period one are $\bar{e}_1 > \hat{e}_1$, due to credit limits or uncertainty that the Kyoto Protocol would be implemented. In this case the discounted sum of abatement costs is

$$(2.12)\ \overline{C}_b = \frac{c_1}{2}(M_1 - \bar{e}_1)^2 + \beta \frac{c_2}{2}\{M_2 - (\overline{Q} + M_1 - \bar{e}_1)\}$$

since period two emissions are determined by (2.7). Figure 2 shows calculations of $C_n - \overline{C}_b$, using the same parameter values while varying period one abatement from 0 to 217 million tons $(= M_1 - \hat{e}_1)$. The lower and upper curves correspond to our low and high abatement cost scenarios respectively, and the extreme right values correspond to the entries in Table 2. We see

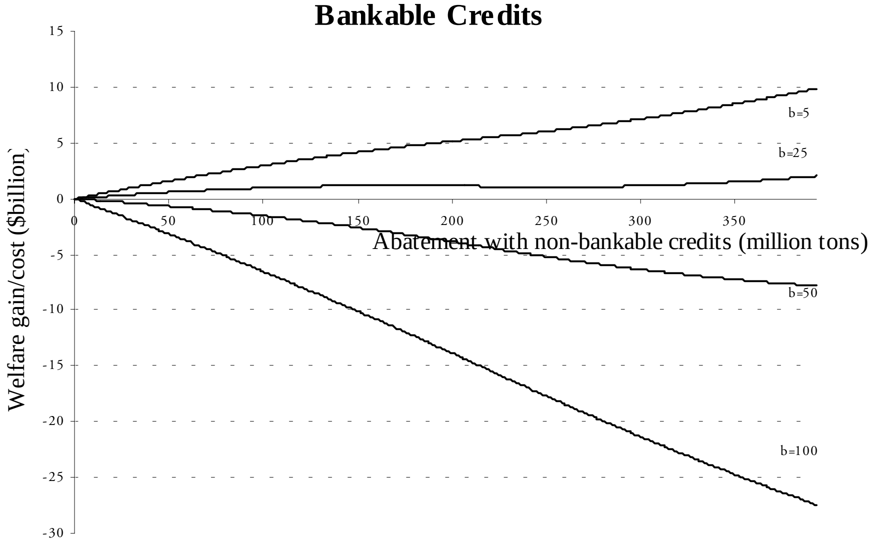
Figure 2. Cost Savings from Bankable Reductions with Credit Limits



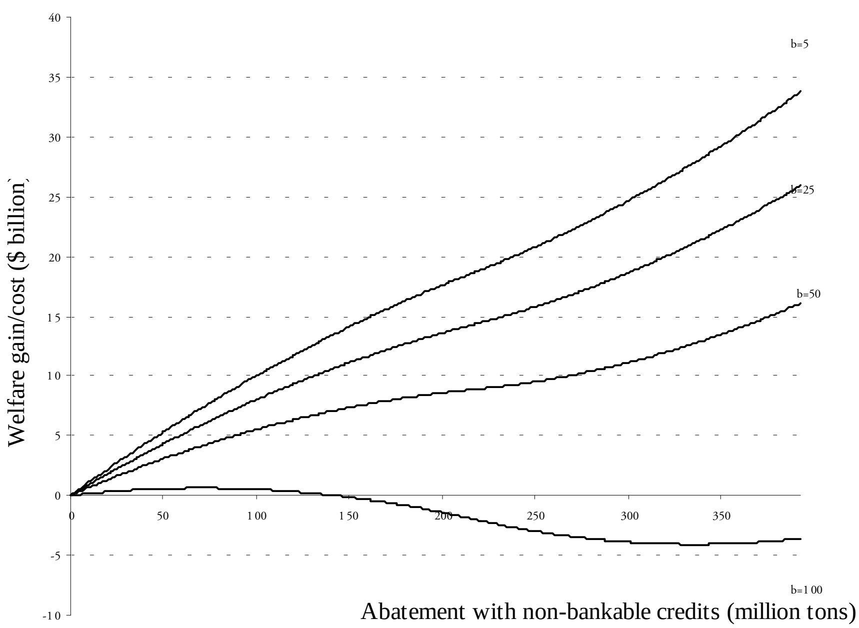
that the cost savings from bankable early reduction credits versus no early credits diminish substantially as abatement falls below the cost-minimizing level of 227 million tons. For example, if early abatement is halved (to 114 million tons) cost savings from aggregate banking are held to $3.1 billion or $9.8 billion, depending on the marginal abatement cost. Figure 2 therefore illustrates the potentially large sacrifice of cost savings when limits are imposed on the allowable amount of bankable credits.

In Figure 3 we compare bankable and non-bankable early reduction credits, in order to show the cost of precluding national-level banking under an early reduction credits program. This cost is obtained by subtracting the net benefits from having non-bankable credits (versus no credits at all) in Figure 1 from the cost savings from having bankable credits (versus no credits at

Figure 3. Net Benefit from Bankable vs. Non-Bankable Credits



(a) Low Abatement Costs



(b) High Abatement Costs

all) in Figure 2.[20] The upper and lower panels again correspond to our low and high abatement cost scenarios, and the different curves reflect alternative scenarios for environmental benefits.

The net gain from allowing aggregate banking relative to non-bankable credits is greatest when marginal abatement costs are high and marginal environmental benefits are low. In this case the value of national-level banking to smooth marginal cost across the precommitment period and the commitment period is high, while the opportunity cost of lost environmental benefits when early emissions reduction offsets later reductions is low. For example, when abatement with non-bankable credits is 393 million tons, the net gains from allowing banking is a huge $33.7 billion per annum under the higher abatement cost scenario when environmental benefits are $5/ton. But when abatement costs are lower and environmental benefits are $50 or $100 per ton, allowing banking results in potentially large net losses. In sum, Figure 3 shows that adding aggregate banking to an early reduction credits program would return a net benefit if environmental benefits are $25/ton in either abatement cost scenario, although the net benefit is much larger when abatement costs are high.

For the rest of the paper we use variants of the model of Section 2 without credit limits or aggregate credit banking.

3. The Implications of Asymmetric Information

In this section we expand the basic model to allow for regulatory uncertainty about the extent of abatement at different firms. In cases where anyway reductions are substantial, we show that true abatement activity at low-cost firms is significantly lower in the presence of asymmetric information, and inefficiency arises because marginal abatement costs differ among firms.

The BAU emissions level M in the abatement cost function (2.1) can also be regarded as a technology parameter. As M decreases, the marginal abatement cost function will shift to the right, thereby decreasing the costs of emissions reductions (we mention below the consequences

[20] Note that if, due to a credit limit, abatement was between 227 and 393 million tons in the absence of banking, then if banking were subsequently allowed, the limit would not be binding, and firms would be free to choose the cost-minimizing level of 227 million tons. In contrast, if the limit implies abatement less than 227 million tons in the absence of banking, then abatement would not change if banking were then introduced.

of changes in the slope of the marginal cost function). This improvement may represent, for example, the adoption of a more energy-efficient technology or process that reduces firm emissions per unit of output.

Suppose that starting from a situation in which all firms have the same technology parameter M_H, a fraction ϕ of the firms costlessly improve their technology level to $M_L<M_H$ prior to any early emissions control. At the other $1-\phi$ fraction of firms, the technology level remains at M_H. The technology improvement is not made to reduce emissions per se; it is made to increase private profits. The resulting emissions reductions illustrate the concept of anyway reductions. To keep things simple, we assume that technology levels for each firm in period two are the same as in period one (no dynamic technology evolution).

In the absence of asymmetric information, each firm would equate marginal abatement costs with the discounted future permit price as in (2.5), so that

$$(3.1) \quad \frac{\beta P_2}{c_1} = M_H - e_1^{H*} = M_L - e_1^{L*}$$

where superscript *H* and *L* denote high- and low-cost firms. Aggregating across firms, emissions abatement and abatement costs are, respectively,

$$(3.2) \quad (1-\phi)(M_H - e_1^{H*}) + \phi(M_L - e_1^{L*}) = M_H - e_1^{H*}$$

$$(3.3) \quad (1-\phi)c_1(M_H - e_1^{H*})^2/2 + \phi c_1(M_L - e_1^{L*})^2/2 = c_1(M_H - e_1^{H*})^2/2$$

Suppose that the government can monitor firms' emissions (by, for example, observing fuel inputs) but cannot directly distinguish between low- and high-cost firms—this is private information to the firms. This information asymmetry can create an adverse selection problem: to obtain credits for anyway reductions, low-cost firms may have an incentive to pose as high-cost firms by denying that they experienced a technological improvement. This does not lead to any inefficiency per se; it only has a distributional effect by increasing the share of permit rents allocated to low-cost firms in period two. [21]

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[21] For simplicity, we assume $M_L \geq e_1^{H*}$. If the technological improvement is large enough so that anyway reductions exceed emissions abatement at high-cost firms then $M_L < e_1^{H*}$. In this case, low-cost firms would have to increase emissions above theBAU level in order to pose as high-cost firms.

However, to make themselves indistinguishable from high-cost firms, low-cost firms must produce the same emissions rate by limiting abatement to $M_L - e_1^{H*}$.[22] In this case, using (3.2), aggregate abatement expressed relative to abatement in the absence of asymmetric information is

$$(3.4) \quad 1-\frac{\phi(1-M_L)}{1-e_1^{H*}}$$

where we have normalized $M_H = 1$. In addition, using (3.3), the ratio of aggregate abatement costs with and without asymmetric information is

$$(3.5) \quad \frac{(1-\phi)c_1(1-e_1^{H*})^2/2+\phi c_1(M_L-e_1^{H*})^2/2}{c_1(1-e_1^{H*})^2/2}=1-\phi+\phi\left\{\frac{M_L-e_1^{H*}}{1-e_1^{H*}}\right\}^2$$

For some illustrative calculations, we consider scenarios where the proportion of firms experiencing technology improvements (ϕ) varies between 0.25 and 0.75 and where anyway reductions reduce emissions by 5% or by 15% at these firms ($1–M_L$ = .05 and .15). Consistent with Section 2, we assume that it is optimal for high-cost firms to reduce emissions by 30% ($1-e_1^{H*}$ = 0.3). The resulting values for the expressions in (3.4) and (3.5) are shown in Table 3.

Table 3. Ratio of Abatement and Abatement Costs with and without Adverse Selection

	Fraction of firms with anyway reductions	*Emission reduction from anyway reductions* 5%	15%
Relative abatement level	.25	.96	.88
	.5	.92	.75
	.75	.88	.63
Relative abatement costs	.25	.92	.81
	.5	.85	.63
	.75	.77	.44

[22] If low-cost firms have lower emissions than other firms do, this would indicate to the government that they must have lower abatement costs. In other words, firms would be reluctant to reduce emissions by so much as to arouse suspicion that part of the emissions reduction represents anyway reductions. Given our assumptions, it is straightforward to show that low-cost firms are better off when they obtain credits for anyway reductions and produce e_1^{H*} emissions than when they produce e_1^{L*} emissions but are not credited for anyway reductions.

When anyway reductions are fairly modest, 5%, adverse selection does not make too great a difference—emissions abatement is still at least 88% of abatement without an asymmetric information problem. However, adverse selection is more of an issue when anyway reductions at low-cost firms are 15% and $\phi = 0.5$ or 0.75. Anyway reductions amount to 25% and 36% of total abatement without asymmetric information in these cases. Actual abatement falls to between 63% and 75% of abatement without asymmetric information, and abatement costs fall to between 44% and 63% of abatement costs without asymmetric information.[23]

Lower abatement also implies foregone environmental benefits. The asymmetric information problem causes abatement to fall by $0.25 \times 393 = 98$ million tons or $0.37 \times 393 = 145$ million tons when anyway reductions are 15% and $\phi = 0.5$ and 0.75, respectively. This implies foregone environmental benefits of $2.5 or $3.6 billion when abatement benefits are $25/ton. In the former case ($\phi = 0.5$), abatement costs are lower by $1.9 or $5.8 billion in the low and high abatement cost scenarios respectively,[24] implying a net loss of $0.6 billion or a net increase of $3.3 billion with asymmetric information. In the latter case, net benefits are between -$0.8 and +$4.9 billion. Again, these paradoxical results arise because early abatement is excessive in many of the parametrizations we consider, so the reduction in abatement due to asymmetric information can produce net benefits.[25]

Adverse selection arises in the above analysis because the government decides to accept each firm's emissions behavior as an accurate signal of the firm's cost type. An alternative to this approach (or to a costly program to ferret out firms' types through direct observation) would be

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[23] One can also look at the impact of asymmetric information by asking—for a given level of aggregate abatement with and without asymmetric information—to what extent asymmetric information raises total abatement costs due to the failure to equate marginal abatement costs across firms. We derived a formula to estimate this (for details, see *www.rff.org/~parry/Credits/Sec3.htm*). For the above parameter values, the cost increase is between 1% and 12%.

[24] These figures result from multiplying $7.7 and $23.0 billion, our total abatement cost figures from Section 2, by 0.25.

[25] Our analysis probably overstates the effect of adverse selection somewhat. Suppose that technological progress reduced the slope of a firm's marginal abatement cost curve, rather than causing a rightward parallel shift. In this case there are no anyway reductions that firms want to falsely claim is deliberate abatement: BAU emissions for low-cost firms remain at M_H rather than being below M_H. Thus, there is no adverse selection problem in this case; low-cost firms lose nothing by revealing their type to the government. In other words, there is an important distinction between new technologies that will only be used if firms have to reduce emissions (i.e. technologies that reduce the costs of abatement but not the costs of producing output) and technologies that are privately optimal to adopt in the absence of carbon policies (i.e. technologies that reduce both emissions and the costs of producing output).

to ignore differences in firm types and provide a common baseline to all firms for early reduction credits. However, while this dispenses with the adverse selection problem it gives rise to other concerns. To illustrate, suppose the baseline is BAU emissions for high-cost firms. Then low-cost firms have no incentive to distort their emissions reduction behavior to earn more credits; the system simply grants them credits that include their anyway reductions. While avoiding inefficiency due to adverse selection, this strategy obviously will give rise to distributional concerns as well as aggravating the fiscal issues discussed in Section 5 below. The other extreme would be to set the baseline at BAU for low-cost firms. This would also discriminate against high-cost firms, in that they would have to undertake substantial early emissions reductions without any reward. If this hurdle is too high (that is, if BAU emissions for low-cost firms are below profit-maximizing emissions with early reduction credits for high-cost firms) an inefficient corner solution would obtain with high-cost firms engaging in no early reduction.

4. The Impacts of Learning-by-Doing (LBD)

Programs for early reduction credits also have been advocated on the grounds that they will encourage firms to innovate and thereby reduce the costs of abatement by the time the Kyoto Protocol comes into force. This section considers the possibility of cost-reducing abatement innovation through learning-by-doing (LBD). We analyze the efficiency of early reduction credits at promoting LBD and calculate by how much LBD might reduce the overall costs of early reduction credits.

(i) The Impact of Early Reduction Credits on LBD

For simplicity we return to the assumption of homogeneous technology in the firms' abatement cost functions (2.1), represented here by the parameters $M_1, \tilde{M}_2$ in periods one and two, respectively. In period one, M_1 is given. In period two, the state of technology at a particular firm i is given by

$$(4.1) \qquad \tilde{M}_2^i = M_2 - \alpha\left\{\theta(M_1 - e_1^i) + (1-\theta)\frac{1}{N-1}\sum_{j\neq i}(M_1 - e_1^j)\right\} \leq M_2$$

where $0 \leq \alpha \leq 1$, $0 \leq \theta \leq 1$, N is the number of firms, and M_2 is the technology parameter in the absence of LBD. Equation (4.1) says that the period two technology parameter depends on a weighted sum of early abatement by the firm and by all other firms together. The greater is α, the

greater is the impact of first period abatement activity on lowering future abatement costs through LBD. When $\theta = 1$, this represents the extreme case when all LBD is firm-specific, and new knowledge is effectively a pure private good. At the other extreme when $\theta = 0$, all LBD is general, and knowledge is a pure public good.

We can now distinguish between a socially optimal outcome in which a central planner took into account all the interdependencies of firms' period one abatement activities and period two technology parameters, and an uncoordinated market equilibrium in which firms take into account only the LBD arising from their own early abatement activity. The gap between these two outcomes is one of the rationales offered for implementing an early reduction credits program to stimulate more abatement and thereby achieve more LBD. In the former case, the central planner views the period two technology parameter as being determined by

$$\tilde{M}_2 = M_2 - \alpha(M_1 - \bar{e}_1) \leq M_2 \qquad (4.2)$$

where $\bar{e}_1$ is average period one emissions across all firms. In the latter case, the private benefits from LBD are effectively seen as being determined by

$$\tilde{M}_2 = M_2 - \alpha\theta(M_1 - e_1) \qquad (4.3)$$

where e_1 is the firm's own abatement.

To explore how efficiently early reduction credits promote LBD, it is helpful to compare the outcome of a market equilibrium with early reduction credits to the outcome with the central planner seeking to minimize the present value cost of meeting the period two emissions quota. In addition, we look at LBD in the absence of early reduction credits: here the rationale for early action by individual firms is limited to efforts to reduce abatement cost in the commitment period. These three problems are denoted with the subscripts *c*, *s*, and *n* respectively. In order to focus purely on the LBD argument for early reduction credits, we ignore any direct environmental benefits from early abatement.

The proportionate emissions reduction in the first period, and the equilibrium permit price in the second period, are given by[26]

[26] See *http://www.rff.org/~parry/Credits/Sec4.htm]* for the derivations.

(4.4a) $$\frac{M_1 - e_{1c}}{M_1} = \frac{\beta P_{2c}\{1+\alpha\theta\}}{c_1 M_1}; \qquad P_{2c} = \frac{c_2(M_2 - \overline{Q})}{1+\alpha\beta(1+\alpha\theta)c_2/c_1}$$

(4.4b) $$\frac{M_1 - e_{1n}}{M_1} = \frac{\beta P_{2n}\alpha\theta}{c_1 M_1}; \qquad P_{2n} = \frac{c_2(M_2 - \overline{Q})}{1+(\alpha\theta)^2 \beta c_2/c_1}$$

(4.4c) $$\frac{M_1 - e_{1s}}{M_1} = \frac{\alpha\beta P_{2s}}{c_1 M_1}; \qquad P_{2s} = \frac{c_2(M_2 - \overline{Q})}{1+\beta\alpha^2 c_2/c_1}$$

We obtain numerical solutions to these equations using the following parameter values. We set θ at 0, 0.5 and 1. These figures imply that the private benefits from LBD are 0%, 50%, and 100% of the social benefits. We also set α equal to .05 and .3, implying that if emissions abatement is x% in the precommitment period, then the costs of reducing emissions by x% in the second period would fall by either 5% or 30% in the central planning case.[27] In addition, we use the same values for c_1/c_2, M_1, M_2, $\overline{Q}$ and β as in Section 2.

Table 4 shows the proportionate amount of period one abatement under each policy. There are three main points from this table. First, LBD by itself justifies a pretty modest amount of abatement in the precommitment period: in the social planning case, early emissions abatement is only 1% to 7% under alternative assumptions about the reduction in period two abatement costs from LBD. Second, even without early reduction credits there is typically some early abatement, depending on how much LBD is firm-specific. For example, when half the LBD is firm-specific, then early emissions abatement is about 50% of that in the social planning case. Indeed, if all LBD were firm-specific, then the socially optimal amount of LBD would be induced without any reduction credits. Third, if we look only at the benefit of early action in stimulating innovation, then early reduction credits generate far too much early abatement in our model.[28] This is because firms obtain a direct monetary reward for early emissions reduction that swamps the private benefits from LBD.[29] The extent to which LBD is general or firm-specific has little net impact with early reduction credits. The more firm-specific LBD is, the greater the

[27] It seems unlikely to us that LBD could reduce abatement costs by more than 30% in the next ten years.

[28] Obviously, this would be tempered if there were limits on credit availability.

[29] Note from the numerator for $(M_1\text{-}e_{1c})/M_1$ in (3.3a) that the private benefits from innovation relative to the private benefit from early abatement is $\alpha\theta$, that is, the product of two fractions.

(private) benefits from LBD. However, more LBD reduces future abatement costs and hence the expected permit price, thereby reducing the incentive to obtain early reduction credits.

Table 4. Proportionate Emission Reduction in Period One with Learning-by-Doing

LBD parameter, α	*Policy*	*Private relative to social cost savings, θ*		
		0	.5	1
.05	credits	.23	.23	.24
	no credits	0	.01	.01
	central planner	.01	.01	.01
.15	credits	.21	.22	.24
	no credits	0	.02	.03
	central planner	.03	.03	.03
.30	credits	.19	.21	.24
	no credits	0	.03	.07
	central planner	.07	.07	.07

(ii) The Cost savings from LBD

We now explore the magnitude of the benefits from LBD under early reduction credits. In particular, we calculate the following formula:

$$\text{(4.5)} \qquad \frac{\beta\left\{c_2(M_2-\overline{Q})^2/2 - c_2[M_2-\alpha(M_1-e_{1c})-\overline{Q}]^2/2\right\}}{c_1(M_1-e_{1c})^2/2}$$

This is the discounted value of the reduction in period two abatement costs due to LBD in the first period expressed relative to the costs of early reduction credits in period one.[30] Some manipulation gives

[30] Note that in practice the benefits from LBD in the first period would extend beyond the commitment period. However, in the absence of early reduction credits, LBD would begin in the commitment period rather than period one. In effect, early reduction credits bring the dynamic path of LBD forward by one period, and in this sense the benefits are one-shot.

$$(4.6) \qquad \frac{\beta\left\{\left(\frac{M_2-\overline{Q}}{M_1}\right)^2-\left[\frac{M_2-\overline{Q}}{M_1}-\alpha\left(\frac{M_1-e_{1c}}{M_1}\right)\right]^2\right\}}{\frac{c_1}{c_2}\left(\frac{M_1-e_{1c}}{M_1}\right)^2}$$

Using $(M_1\text{-}e_{1c})/M_1$ = .23 from Table 4 and our previous values for β, c_1/c_2, M_1, M_2 and $\overline{Q}$, the value of this expression is .1 (α=.05) or .54 (α=.3). In other words, taking into account the benefits of LBD can still offset a substantial amount—10% or 54% in our cases—of the cost of early reduction credits.

(iii) R&D-Based Innovation

Suppose instead that abatement costs in the second period can be reduced by investing in R&D in the first period. We would expect firms to under-invest in R&D for the usual reasons: the private benefits from improving the technology level often are less than the social benefits due to the public good nature of new knowledge. However, in this case early reduction credits would have no effect on technological innovation, because they have no impact on the amount of emissions abatement in period two, and hence no impact on the return from innovation.[31] Promoting more R&D-based innovation then would require additional policy instruments such as research subsidies or prizes.

5. Fiscal Implications of Early Reduction Credits

On welfare grounds, there is potentially a very strong case for auctioning emissions permits rather than giving them out for free. A number of studies have demonstrated the large welfare gains to be had if revenues from permit sales are used to reduce the rates of preexisting distortionary taxes in the economy.[32] In this section, we consider the welfare implications for early emissions credits if future permits were to be auctioned rather than grandfathered.

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[31] Only to the extent that new technologies could be invented and also diffused within the five-year precommitment period could early one-shot abatement provide any incentive for additional R&D.

[32] See, for example, Parry et al. (1999). There are other welfare dimensions along which auctioned and grandfathered permits may differ, but these are probably less important empirically for early reductions programs. For example, in theory, auctioned permits generate more innovation than grandfathered permits, but the additional

Suppose then that the government plans to sell off all residual permits in period two at the market price and use the revenues to cut distortionary taxes, such as the personal income tax. Returning to the model of Section 2, the (discounted) welfare gain from this revenue recycling effect under emissions credits is given by

(5.1) $$\beta P_2(\overline{Q} - R)\eta = \beta P_2(\overline{Q} - (M_1 - \tilde{e}_1))\eta$$

where $R = M - \tilde{e}_1$ is the total quantity of early reduction credits. $P_2(\overline{Q} - R)$ is the revenue from permit sales, net of the permits that are awarded for earlier reductions. η is the *marginal excess burden of taxation*. This is the increase in the deadweight cost of the tax system from the tax increase necessary to raise one more dollar of tax revenue. Allowing for the impact of the tax system on distorting factor markets and on distorting the pattern of spending between items that are tax deductible and those that are not, we assume a value for η of 0.4.[33]

In this case, then, giving out early reduction credits involves an indirect welfare cost—it reduces the amount of revenues raised from sales of future permits and hence the potential welfare gains from cutting distortionary taxes.[34] From (5.1), this welfare loss is $\beta P_2(M_1 - \tilde{e}_1)\eta$. This can be compared to the total cost of abatement in period one, $c_1(M_1 - \tilde{e}_1)^2/2$. Using (2.5), the ratio of these two terms is simply $2\eta c_2/c_1$. Given our values for η and c_2/c_1, the welfare loss from reducing the revenue from future permit sales would raise the overall costs of early emissions reductions by 75%—a very substantial amount.[35]

6. Early Reduction Credits versus Early Cap-and Trade

Economists have long advocated formal allowance-based emissions trading, where institutionally feasible, over more restricted credit-based systems (e.g., Stavins, forthcoming).

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welfare gain from this is typically small (Fischer, Parry, and Pizer 1998). For a more general discussion of the issues see Fischer, Kerr, and Toman (1998).

[33] See Browning (1987) for an insightful discussion of the marginal excess burden of taxation. The above value is taken from Parry (1999), which allows for tax deductions.

[34] Alternatively, reduced revenues imply less government spending. If the social benefits per dollar of this spending are greater (less) than $1+\eta$ the welfare cost of reduced revenue would be greater (less) than above.

[35] A complete analysis of how preexisting tax distortions affect the welfare impact of emissions abatement policies would require a general equilibrium model that captures how the changes in relative product prices caused by abatement policies feed into tax-distorted factor markets. This has been termed the tax-interaction effect in other studies (e.g., Parry et al. 1999).

Emissions trading is seen as providing more efficient exchange with lower transactions cost and more credible environmental performance, because there is no need to worry about case-specific baselines for credit determination. This is the reasoning that lies behind economists' support for emissions trading over a credit-based approach when and if GHG emissions limits are imposed. However, the situation with early reduction credits is somewhat different. Here we need to compare voluntary early emissions reductions to the imposition of a mandatory regulatory structure that, at least in some ways, foreshadows what would be done once the commitment period begins.

It is straightforward to show that in the simplest case with no adverse selection and with a given amount of abatement induced in the first period, the costs and net benefits of a binding cap-and-trade program in period one are identical to those under early reduction credits, whether permits or credits are bankable in the aggregate or not. However, this observation leaves out a number of important practical differences between the two approaches.

First, an early cap-and-trade program can be established regardless of the expected policy regime in the commitment period. The incentives for control depend on the total emissions cap in the precommitment period, not on the expected price of permits in the commitment period. This means that one can avoid the potential for excessive abatement in the precommitment period caused by an inefficiently stringent constraint in the commitment period.[36] By the same token, it means that one can actually engender early abatement for whatever reasons—reaping environmental benefits, encouraging learning-by-doing, and experimenting with policy institutions—even if there is uncertainty about the regulatory regime in the commitment period.[37] Under the early cap-and-trade program, moreover, permits can be auctioned or awarded based on

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[36] Ideally, one would like a dynamically optimal system that provides the right degree, as well as means, of emissions control across both periods. Our analysis here is a second-best scenario, in that it takes the commitment period targets as given. This is, of course, what gives rise to the potential for benefit from aggregate banking of early emissions reduction credits discussed in Section 2.

[37] An early cap-and-trade program secures a definite level of emissions in the precommitment period, while abatement under an early reductions credit program would be uncertain because of uncertainty over current abatement costs and the future permit price. Because the early reduction credits program would not have a fixed target, it would not be subject to the same compliance-cost uncertainty as a simple cap-and-trade system. However, the hybrid approach advanced by Pizer (1997, 1999) and Kopp et al. (1999) provides a safety valve which limits the compliance-cost risk in the cap-and-trade system. With this modification, any advantage the credit-based system might offer in terms of reducing compliance-cost uncertainty can be provided more efficiently in a cap-and-trade approach.

emissions before, rather than during, the precommitment period. In either case, there is no adverse selection problem.

Moreover, the welfare cost of crowding out future revenues from permit sales is avoided if a permit system is used in period one, because it does not induce any reduction in the quantity of period two permit sales. If period one permits were also auctioned and recycled in tax cuts, there would be an additional welfare gain. Thus, in the case where the government plans to auction future permits rather than grandfather them (hence reducing the need to raise revenues from other distortionary taxes), there is a potentially large welfare cost to using early emissions reduction credits over a cap-and-trade program in the precommitment period.

For all these reasons, therefore, we think there is a decisive argument in favor of a cap-and-trade approach over early reduction credits if one wishes to pursue early emissions reductions. Whether an early cap-and-trade system generates net benefits depends, to be sure, on the stringency of its targets. But based on Figure 1, and assuming benefits of $25/ton, an early cap-and-trade program that reduced emissions by around 100 million tons (or about 6%) could be worthwhile, even if abatement costs turn out to be relatively high.

7. Concluding Remarks

An early emissions reduction credits program could produce very substantial cost savings, amounting to several billion dollars per annum, if such credits could be used to offset future emissions in the compliance period. Without the aggregate banking provision, the net benefit of having an early reduction credits program depends greatly on current and future GHGs abatement costs (the latter through their impact on the expected future shadow price of carbon). A program could produce substantial net losses if climate change mitigation benefits are relatively modest and abatement costs relatively high. A cap-and-trade permits program offers a number of advantages over early reduction credits, including: more flexibility in setting the stringency of the early emissions reduction program; the capacity to avoid problems of adverse selection associated with an early reduction credits program; and the ability to produce indirect efficiency gains through raising revenue to offset other distorting taxes (whereas early reduction credits could exacerbate such distortions by crowding out future auction permit revenue).

Our analysis abstracts from a number of other considerations that might be pertinent to the design of early emissions reduction programs. Binding limits on the quantity of early

reduction credits could significantly inflate costs by encouraging rent-seeking expenditures, because firms would be competing against each other for a fixed amount of credits. Completely predictably, we do observe large emissions sources and company trade associations incurring lobbying costs in an effort to influence the rules for defining and awarding early reduction credits. However, similar incentives for rent-seeking would exist under an early cap-and-trade program with grandfathered permits. Estimating the magnitude of these additional deadweight losses is difficult, because the portion of program rents that would be dissipated in rent-seeking is not really known before the fact.

Early reduction programs also have been advocated on the grounds that they provide participants with experience in trading, and that they create political momentum toward broader and deeper GHG limits. As for the former point, we note that almost without exception, advocates of GHG trading favor the evolution of some kind of cap-and-trade system. A less well-structured, credit-based program for early emissions reduction thus does not provide much valuable institutional learning about trading over the longer term. As for political momentum, any early reduction credits program will create winners and losers. Concern about these distributional effects will be amplified if the qualifying criteria for projects that generate early reduction credits programs are not transparent, as is inevitable in a more ad hoc credit-based system. Advocates of a credit-based approach will have to consider how much the controversy thus engendered could undermine momentum toward stronger future action.

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