The Simple Analytics of Greenhouse Gas Emission Intensity Reduction Targets

by

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ABSTRACT

The Bush Administration followed its March 2001 withdrawal from the Kyoto Protocol by a February 14, 2002 proposal for unilateral action to reduce the intensity of US greenhouse gas emissions, with intensity defined as emissions per unit of GDP. The idea is to focus on the rate of decline of the emissions intensity of the economy, rather than the total amount of emissions (though the two are obviously related). In this paper we examine the characteristics of a goal of a rate of decline in intensity. We present a simple model and show that in order to stabilize greenhouse gas concentrations, the rate of decline in intensity must equal the rate of growth of GDP. Additionally, we show that cost uncertainty can be reduced through the use of intensity reduction targets.

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I. INTRODUCTION

The very emphatic withdrawal of the Bush Administration from the Kyoto Protocol in March, 2001 suggests that there is no US policy on climate change. This view is reinforced by the 2002 Valentine’s Day announcement from the Bush Administration that the cornerstone of its climate policy is to set a goal to reduce the greenhouse gas intensity of the US economy by 18% over the coming decade; never mind that this was roughly the rate at which the economy had been “de-carbonizing” over the previous decade.

Despite the fact that the level of effort for reducing US emissions implied by the Bush proposal is modest or non-existent, there are elements of the proposal that are innovative, at least in principle. In this paper we take a closer look at the much-maligned Bush approach of focusing on declining greenhouse gas intensity in the economy. Although its voluntary nature makes it not much of a policy, the approach has innovative dimensions, addressing at a general level some of the problems associated with the quantity targets approach of Kyoto.

II. THE POLICY CONTEXT

In March 2001, U.S. President George W. Bush announced that the U.S. would not be a signatory to the Kyoto Protocol. There is no point in providing another review of the context of the President’s withdrawal of the U.S. from the Kyoto Protocol; in any event, it is unclear whether the U.S. Senate would ever have ratified the Protocol.²

² It is far from clear how damaging Bush’s decision was to global climate policy. It could be argued that dragging out the Kyoto process only to have it rejected by the US Senate some time in the future would be worse. Refer to the op-ed piece by David Victor in the New York Times, “Piety at Kyoto Didn’t Cool the Planet;” (March 23, 2001); and his
On February 14, 2002, the President announced his “new approach” to a climate strategy,\(^3\) a set of unilateral actions to be undertaken by the U.S. Although many observers feel the initiative is weak and largely ineffective, it is important to separate the strength of the initiative from the substantive approaches to the climate problem suggested by the initiative. In other words, there are innovative ideas in the proposal; it is in large part because they are applied weakly or voluntarily or both that the net effect is so modest.

The cornerstone of the Bush proposal is a focusing on reducing the greenhouse gas intensity of the U.S. economy,\(^4\) rather than setting a fixed cap on emissions, as proposed in Kyoto.\(^5\) The goal of reducing greenhouse gas intensity seeks to decouple growth in output and consumption from greenhouse gas emissions reduction. Although GDP decreases are a way of reducing emissions (witness the case of Russia in the 1990’s), it is not a popular strategy, nor likely to be very effective in the long run. A country whose economy is in the doldrums is unlikely to want to invest much in environmental protection. A reduction in the greenhouse gas intensity of production inevitably means a change in the structure of production (moving away from greenhouse gas intensive industries) as well as pursuing proactive measures to control emissions, such as switching from coal to natural gas in electricity production and reducing vehicle kilometers traveled by auto.

Table I shows the reduction in greenhouse gas intensity in the US and selected other countries over the decade of the 1990’s. As can be seen, the greenhouse gas intensity of the US


\(^4\) Although the emphasis on reducing intensity has achieved new prominence through the emphasis it has received in the Bush proposal, it is not a new concept. In fact, the German industry has couched its voluntary agreement on reducing greenhouse gases as a commitment to reduce the intensity of greenhouse gas emissions in individual German industries.

economy “naturally” declined by 17% over the 1990’s with most of that occurring in the last five years of the decade.\(^6\) It is unlikely that this was due to any action by the US Government; rather, it resulted from structural change (and perhaps some technological change) in the economy with a gradual movement away from greenhouse gas intensive industry. In this context, the Bush Administration goal of a reduction of 18% over the decade ending in 2012 should be an easy target to hit.

In terms of improvements in greenhouse gas intensity of the economy, the record of other Annex I countries during the period is quite similar to that of the US.\(^7\) Germany and the UK did very well (much better than the US) in reducing the greenhouse gas intensity of its economy, though the absorption of East Germany made this somewhat easier for Germany and the introduction of North Sea gas (and phase out of coal) made this easier for the UK. The EU minus Germany (“EU-14”) performed almost identically to the US in terms of reducing greenhouse gas intensity (though the overall intensity is considerably lower than that of the US). The EU minus Germany and the UK (“EU-13”) did not do as well as the US in terms of the decline of intensity. On the other hand, all European countries have economies which are much less greenhouse gas intensive than the US. Focusing on the reduction of greenhouse gas intensity, the US looks good; focusing on the absolute level of greenhouse gas intensity, the US looks much less noble.

A glaring omission in the Bush proposal on reducing greenhouse gas intensity is that there are precious few mechanisms stipulated for implementing the goal of reducing intensity. The goal is just that – a goal – and there are no regulations and few other steps proposed to accomplish the

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\(^6\) Table I excludes land use change and forestry (so-called LULUCF) from greenhouse gas emissions. Had those been included, the figures would be somewhat different, though the general picture would remain the same.

\(^7\) An examination of other Annex I countries for the 1990-99 period indicates a similar pattern. The FCCC and the OECD report data on 18 Annex I countries for 1990 and 1999. The median decline in greenhouse gas (excluding LULUCF) intensity is 14.1%; the US decline is 16.1%; Germany and the U.K. have the greatest decline, of approximately 29%; intensity in Ireland, Switzerland and Italy actually goes up by 10-15%.
goal. The Bush proposal does indicate that there will be a reassessment in 2012 and if progress is slow or the “science” is more alarming, further steps will be taken. However, the public record is littered with goals in energy conservation, environmental cleanup and in other arenas, goals which are subsequently not met; generally the only consequence of an unmet goal is to regret the optimism of goals set in an earlier more naive time.  

III. THE ISSUES: QUANTITIES VERSUS INTENSITY RATES

One of the major components of the Bush Climate Plan is the concept of moving away from committing to a national emission cap by a specified date (such as is embodied in Kyoto) to a targeted rate of decline in the emissions intensity of the economy. Leaving aside the issue of the strength of the Bush proposal, it is worth examining the relative merits of a cap on overall emissions vs. an agreement on a rate of reduction in emissions intensity.

It is appropriate to emphasize that a targeted rate of decline in the emissions intensity is not the same as a growth indexed cap. A targeted rate of decline (say 3% per year) applies indefinitely and specifies a continuing rate of decline in intensity. A cap applies to a particular point in time and is not a continuing target. A growth index cap is still a cap; it is just that the size of a cap set in advance is adjusted, depending on the amount of economic growth that occurs between the time the cap is set and when it goes into effect. Thus there is not a real symmetry here.

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8 One classic unmet goal is the goal of attaining ambient air quality standards, a goal set out in the US Clean Air Act of 1970. After thirty years, the best measure of the extent to which the goal has been met is the number of days a year the standards are violated – down to less than 100 in some of the most polluted cities, such as Houston and Los Angeles.

There are two fundamental dimensions of climate policy upon which we will focus this analysis: dynamics and uncertainty.

A. Dynamic Issues

It is important to realize that the Kyoto Protocol has been a long time in the making. The Protocol was negotiated (at least in its initial form) in 1997 and keyed off of emissions in 1990. The Protocol calls for each developed (Annex I) country to reduce annual emissions in the period 2008-2012 to about 5% below what they had been twenty years earlier (1990). It is now 2003, six years after Kyoto, and we are still debating the ratification of the protocol. These are very long time frames. Furthermore, no sooner will we have settled on Kyoto targets and the signatories than it will be time to embark on another round of negotiations, for the so-called second commitment period, possibly with associated additional emission reductions.

This is a key issue. The use of national caps on emissions implicitly involves repeated negotiations, at least until the point occurs when all countries are brought into the protocol so that all emissions may be stabilized. The same parties must come together every decade or two to renegotiate new emission targets. This leads to dynamic incentive problems, first identified in the context of central planning in the Soviet Union -- the *ratchet effect*. If an agent knows that his performance in period n will influence his negotiating position in period n+1, there is an incentive to bias performance in order to enhance the negotiating position. In the context of the Kyoto Protocol, a country that does well in meeting its commitments will be rewarded by further

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10 As of May, 2003, the Kyoto Protocol still does not have enough signatories for the Protocol to go into effect.
11 There are many environmental examples of the ratchet effect. Consider the problem of setting automobile emission standards. In the US in the 1970’s, the government promulgated challenging automobile emission standards. The auto companies were faced with a conundrum. If they tried hard and met the tough standards, they knew their reward was to be subject to even tighter standards in the next negotiating period – their good performance would be rewarded by ratcheting up the expectations in subsequent regulatory interactions.
required reductions in the subsequent commitment period: good citizenship does not pay. Not only is this not fair but it creates incentives for poor performance.

This problem can be solved by precommitting to a path of emissions, eliminating the need for repeated renegotiation. Of course there are many ways of defining a path of emissions, though there is some appeal to simplicity and a formulaic path. The idea of committing to a rate of reduction in greenhouse gas intensity of the economy (x% per year) has the advantage of simplicity while at the same time providing a continually changing target for emission reductions, with the changes predetermined. Of course if the agreed rates of reduction are subsequently viewed as inadequate, then renegotiation will be necessary.

B. Uncertainty

One of the major concerns with the Kyoto Protocol for many countries has been the cost of meeting the targets. Will it be easy (cheap) or tough (expensive)? Information on control costs is sketchy since the world has had very little experience with reducing emissions of greenhouse gases; in any event, the reductions will not be at their strictest until 2012 or so – far into the future. The fear has been that a country would commit to a cap on emissions and then find that the cost of abatement was exceptionally high. For instance, if a marketable permit system were implemented for a country’s cap, the fear was that the price of a permit might be very high. The fear was not helped by the great deal of variation in the estimates of the marginal cost of emission control associated with Kyoto limits.

There have been a number of proposals for dealing with this uncertainty and putting a cap on the marginal cost of emission reductions. These proposals took many forms but one of the

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most popular was associated with domestic trading schemes for carbon. The assumption was that the Kyoto targets would be implemented with some sort of cap and trade system for greenhouse gases: a country would issue permits for its allowed emissions and trading in those permits would proceed. The “safety valve” idea was that the government would sell additional permits at a predetermined price – for example, $25 per tonne of carbon. This is a variant on the permit system proposed by Marc Roberts and Michael Spence some years ago.\(^\text{13}\)

On the one hand, the safety valve approach assures that the marginal cost of carbon control would never exceed the price of extra permits. On the other hand, should extra permits be issued, then the quantitative limits of the Protocol would be abrogated. This has made many, particularly environmentalists, wary of allowing a safety valve of this sort.

For an individual country, uncertainty in the costs of meeting the Kyoto targets comes from two primary sources. One is that there is uncertainty about the overall level of economic activity in the country, come 2012. High levels of growth over the 1990-2012 period mean that the target is much harder to “hit.” Low or negative levels of growth (e.g., Russia) make for easy targets. The second source of uncertainty regards the cost associated with reducing greenhouse gases, holding the level of economic activity constant.

IV. THE ANALYTICS OF INTENSITY CHANGE TARGETS

In the previous section we reviewed some of the broad issues related to an emissions cap – the approach taken in the Kyoto Protocol – and a target rate of reduction in greenhouse gas intensity – the approach proposed by the current U.S. Administration. We first take a look at the


dynamics of stabilizing greenhouse gas concentrations, the goal of the Framework Convention on Climate Change (FCCC), to which the US and many other countries are signatories. We then look at the question of uncertainty and the nature of a safety valve under either an emissions cap or a targeted rate of reduction in emissions intensity.

A. Decomposing Intensity

The stabilization of greenhouse gas concentrations is the stated goal of the Framework Convention on Climate Change. Fundamentally, this translates into eventually achieving zero growth in net emissions; presumably that will ultimately be reflected in Kyoto, son-of-Kyoto or other subsequent protocols to implement the FCCC.

For a given country, let $G(t)$ be the total emissions of greenhouse gases in year $t$ and $Y(t)$ the net economic output in year $t$. Define the greenhouse gas intensity, $g(t)$, by the quotient:

$$g(t) = \frac{G(t)}{Y(t)} \quad (1)$$

Solving Eqn. (1) for $G$, differentiating with respect to $t$, and manipulating yields

$$\frac{\dot{G}}{G} = \frac{\dot{Y}}{Y} + \frac{\dot{g}}{g} \quad (2)$$

The interpretation of Eqn. (2) is that the growth rate for greenhouse gas emissions is the sum of the growth rate for economic output and the growth rate for intensity. Since, for structural reasons, the growth rate for intensity is typically negative (see Table I), the growth rate in output exceeds the growth rate in greenhouse gas emissions. In order to stabilize concentrations, it is
necessary to ultimately achieve zero net growth in emissions, which means that the growth rate in output must eventually equal to the rate of decline of greenhouse gas intensity.\textsuperscript{14}

Clearly, the rate of growth of greenhouse gas emissions can be affected by reducing the rate of economic growth. Most countries, however, would probably prefer to focus efforts on reducing the intensity without retarding growth. In fact, this has been a big issue with developing countries, who have strongly argued that their economic development should not be slowed by greenhouse policies.

In order to understand the dynamics of changes in the greenhouse gas intensity, we first step back and explore the determinants, at a macro level, of greenhouse gas emissions. At a very aggregate level, and for a given country, emissions at a point in time, \( t \), depend on the overall level of economic activity, the level of effort in emissions abatement, and the overall structure and technology of the economy. This last component, dependent only on the passage of time, \( t \), has to do with the overall level of technology in the economy as well as the structure and composition of the economy; it is largely outside the control of national governments. The abatement effort, \( E \), involves costly resources being invested to reduce the intensity of production. Without loss of generality, assume \( E \) is denominated in monetary units – expenditures to achieve abatement. In sum,

\[
G(t) = F(t, E(t), Y(t)) \tag{3}
\]

The function \( F \) in Eqn (3) should be homogeneous of degree 1 in \( E \) and \( Y \); doubling of the size of the economy and the amount of effort should lead to a doublng of the greenhouse gas emissions, \textsuperscript{14}

\textsuperscript{14} The US economy grew by 38\% in the 1990’s yet the intensity only declined by 17\% (Table I), leaving a substantial gap. The economy of the EU minus Germany grew by 24\% while its intensity declined by 17\%, leaving a more modest gap.
holding \( t \) fixed.\(^{15}\) We can divide Eqn. (3), and \( F \), through by \( Y(t) \), letting effort normalized by the overall level of output be denoted by \( e(t) \equiv E(t)/Y(t) \):

\[
g(t) = F(t, e(t), 1) \equiv f(t, e(t))
\]  

(4)

Differentiating Eqn. (4) and rearranging yields

\[
\frac{g}{g} = \frac{f_t}{f} + \frac{f_e}{f} \frac{e}{e} \frac{e}{e}
\]

or

\[
\frac{g}{g} = \frac{f_t}{f} + \frac{e}{e} \sigma_E(t) \equiv r_A + r_E
\]

(5)

where

\[
\sigma_E(t) = \frac{f}{ef_e} = \frac{G}{E} \approx \frac{\Delta G}{G}
\]

(6)

and \( r_A \) and \( r_E \) are, respectively, the rates of growth in autonomous greenhouse gas intensity and endogenous greenhouse gas intensity. Eqn. (5) can be interpreted as saying that the rate of decline in greenhouse gas intensity is composed of an autonomous part, related to the passage of time plus a part that requires effort on the part of a country.

What is the interpretation of the \( \sigma_E(t) \)? As the right-hand-most expression suggests, it is roughly the percentage change in effort associated with a percentage change in emissions. With

\(^{15}\) Homogeneity is easy to see through a thought experiment. Take a country like the US or the UK and divide it in half. Each half has half the GDP, half the effort to reduce emissions, and half the emissions.
effort denominated in dollars, this is effectively the marginal cost of emission control, expressed as an elasticity. In fact, it is the change in expenditures on control effort necessary to achieve a unit change in aggregate emissions, expressed in percent change rather than absolute change – it is the elasticity of control costs with respect to emissions. The elasticity is a function of time because we would expect it to decrease over time, as the marginal cost of emission control drops.

Rewriting Eqn. (2), using Eqn. (5), we obtain

\[ r_G = r_Y + r_A + r_E \]  

(6)

which states that the rate of growth in emissions of greenhouse gas is the sum of the rate of growth of output (GDP) plus the autonomous rate of growth of greenhouse gas intensity (generally negative) plus the rate of growth of intensity due to proactive efforts (hopefully also negative). The autonomous rate of change in intensity is difficult to estimate, although from Table I we see that during the 1990’s a rate slightly less than 2% per year was common.\(^{16}\)

The bottom line here is that committing to ultimately reducing intensity at the same rate that GDP is rising is a simple and robust way to commit to a dynamic greenhouse abatement path. It is a more natural target than a quantity target that must subsequently be revised. Of course, agreeing on a rate of reduction and adjusting it as additional information becomes available is not easy.

B. Uncertainty.

\(^{16}\) An examination of nineteen Annex I countries for the period 1990-1999 indicates a median reduction in greenhouse gas intensity of 16% per decade, which translates into slightly less than 1.4% per year. There is, however, considerable variation around this figure, as was mentioned in an earlier footnote.
One of the concerns that many have had regarding the Kyoto Protocol is the cost of meeting the agreed targets. Ironically, for some countries, the cost is zero (or even a net gain); for other countries, the cost is substantial. Although the playing field appears somewhat level in that most Annex I countries need to reduce emissions by about 5% from the baseline year. But the targets are in terms of greenhouse gas emissions, some twenty years after the baseline of 1990. Much can happen in those intervening years resulting in a great deal of uncertainty in costs.

Several things can influence the uncertainty over a country’s cost for meeting a target. One is the size of the required reduction relative to “business-as-usual.” A 20% reduction in emissions is obviously more difficult to accomplish than a 2% reduction in emissions. The second source of uncertainty in cost is simply how much it costs to reduce emissions, holding constant the required emission reduction. Although there are estimates of how much it might cost to achieve a 10% reduction in emissions in a country such as the U.S., there is considerable uncertainty over that figure.

These uncertainties can be decomposed into uncertainty regarding the overall level of economic activity and uncertainty regarding the cost of emission control at the margin, given the level of economic activity. Let $\varepsilon$ be a random variable reflecting the uncertainty regarding GDP in the commitment period. Certainly with a 10-15 year lead between negotiating something like Kyoto and the commitment period, $\varepsilon$ will have a great deal of variability. The fact that US GDP grew so much in the 1990’s resulted in much higher levels of economic output than had been expected. Recall that the US has for sometime had lackluster GDP growth.

The other source of uncertainty regards the “ease” with which the economy can achieve the target greenhouse gas intensity during the commitment period. How that intensity declines over time is not well understood nor easily predicted. Let $\eta$ be a random variable that reflects the
uncertainty in the average cost of greenhouse gas control per unit of output, conditional on the level of economic output and the level of aggregate emissions. We make the assumption that $\eta$ and $\varepsilon$ are independent.

It is clear that under a quantity target for emissions, the cost is more uncertain, depending on two random variables. On the other hand, with a commitment to a reduction in emissions intensity, the uncertainty is less, since the costs are conditional on the level of output, $Y$, and hence the realization of the random variable, $\varepsilon$.

More formally, Eqn. (3) may be re-written, exploiting homogeneity:

$$E(t)/Y(t) = h[t, G/Y(t)] \quad (7a)$$

or, with uncertainty,

$$= h[t, G/(Y(t)) + \varepsilon] + \eta \quad (7b)$$

$$= h[t, g] + \eta \quad (7c)$$

The left-hand-side of Eqn. (7) is the average effort per unit of emissions – the average cost of abatement. Note that if we fix the cap on emissions, $G$, then Eqn. (7b) applies and uncertainty in $E/G$ involves both $\varepsilon$ and $\eta$. Alternatively if we fix the intensity level, $g$, Eqn. (7c) applies and the only uncertainty is that associated with $\eta$.

How might a country implement an agreement to reduce greenhouse gas intensity? If a commitment to a rate of decline translates into an intensity in year $t$ of $g_t$, and the realization of the random variable influencing output is $\varepsilon_t$, then $g_tY(\varepsilon_t)$ emission permits would be issued for that year. Thus every year, the number of permits issued would fluctuate, depending on the realized economic output as well as the agreed level of greenhouse gas intensity.
V. CONCLUSION

We have taken a close look at one idea in the much-maligned February 2002 Bush climate initiative: the idea of targeting on the rate of reduction of the greenhouse gas intensity of an economy (greenhouse gas emissions per unit of real economic output).

One advantage of intensity measures is that they address the problem with the emissions cap approach of Kyoto that requires continual renegotiation of the caps as we proceed through time. As is shown in the paper, focusing instead on achieving a rate of reduction in emissions intensity that equals the long-run rate of growth of GDP effectively stops the growth of global greenhouse gases. (Of course, that may not be enough – it may be important to stabilize at an even lower level.)

Another aspect of the intensity measure is that it does not penalize countries for economic growth, at least in comparison with an absolute cap on emissions. This has been a major problem with the developing world, who view Kyoto-like caps as hindering growth. Decoupling growth from intensity largely neutralizes this criticism. However, even with intensity reduction rates, there is some sensitivity to economic growth, but in a more positive vein: in years where growth is modest for a country, reductions in the intensity target need not be as high.

A further advantage of the intensity measure has to do with reducing the uncertainty over emission control costs. A major impediment for ratification by some countries has been the wide-ranging potential costs associated with the Protocol. The cost uncertainty arises from a combination of uncertainty over how much an economy may grow by the time the commitment period arrives (2012 is 15 years after Kyoto). Cost uncertainty also arises from simple uncertainty over how difficult it is to control emissions, given a particular level of economic activity. The rate
of reduction in intensity target has the advantage of resolving the uncertainty over economic growth – emissions are conditional on the level of economic activity. Thus overall uncertainty is reduced.
Table I: Greenhouse Gas Emissions (excluding LULUCF) and Emission Intensity, 1990-2000

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>GHG Emissions</th>
<th>GHG Change (%)</th>
<th>GHG Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1990</td>
<td>1995</td>
<td>2000</td>
</tr>
<tr>
<td>US</td>
<td>6131</td>
<td>6482</td>
<td>7001</td>
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<tr>
<td>EU-15</td>
<td>4216</td>
<td>4088</td>
<td>4068</td>
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<tr>
<td>EU-14 (EU-15 less Germany)</td>
<td>2993</td>
<td>3017</td>
<td>3077</td>
</tr>
<tr>
<td>EU-13 (EU-15 less Germany &amp; UK)</td>
<td>2251</td>
<td>2332</td>
<td>2428</td>
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<td>Japan</td>
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<td>UK</td>
<td>742</td>
<td>685</td>
<td>649</td>
</tr>
</tbody>
</table>

Notes:
1. Source: GDP data from OECD National Accounts; GHG data from FCCC database.
2. Units for GHG: Millions of metric tones of CO2 equivalent
4. GHG Intensity: kg of CO2-equivalent per $GDP
5. GHG Emissions omit LULUCF – Land Use, Land Use Change, and Forestry