IEA – EMF – IEW Workshop, Paris, June 1999.

Choice of Instrument and Cost of Response: the Dynamically Efficient Policy Mix

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Abstract

Application of the Allocating Permits Usefully proposal (Appendix 1 – see also web-site http://econ.massey.ac.nz/APU) enables the price signal to abatement innovations to be separated from the price signal to consumers. Non-linear dynamic programming taking account of learning by doing shows that, except at the policy time horizon, it is always cost minimizing to offer a higher price to the marginal innovator than the deterrent imposed on emitters. The more distant the time horizon, the greater is the dynamically efficient incentive to innovation under an assumption of progressively intensified policy commitments. In the early years of the dynamically efficient policy, the combination of innovation incentive and emissions incentive is equivalent to a tax dedicated to abatement innovation, yielding no permit auction revenue (or 'pork barrel' with grand-fathering of permits), and therefore equivalent to Proportional Abatement Obligations). Subsequently an increasing potential 'pork barrel' is available, eventually leading to the pure emissions permit case in the final time period. Policy relevant conclusions are a) that policy makers cannot minimize discounted policy costs through use of conventional price signals and b) that efficient policy design requires the early adoption of indicative emissions reduction commitments over a long time horizon.

Introduction

Proportional Abatement Obligations (PAO's – formerly Tradeable Abatement Obligations and Tradeable Absorption Obligations or TAO's) – were proposed originally as an instrument for promoting a biofuel oriented GHG response strategy (Read, 1994). They have been seen as an alternative to conventional price signaling instruments (emissions charges or tradeable emissions permits). Their comparative static properties have been analyzed vis-à-vis price signals (Read, 1999 – see concluding paras of Appendix 1 for a summary) and some of their geo-political-economic features discussed (Read, X,Y,Z). Despite comparative static inefficiency, it has been shown, in an analysis that takes account of learning by doing with abatement technologies, that the PAO is lower international commitment, and the PAO securing the dynamic pattern of investment in abatement innovation that yields least aggregate discounted cost.

In this paper we first briefly review the theoretical background, then we develop a simple dynamic model and present some results for the optimum mix of TEP and PAO in cases of interest. These are derived from non-linear dynamic programming for which the coding is detailed in Appendix 2. In concluding, directions for future research are indicated.

Background

Complex non-linear dynamics theory suggests the likely existence of thresholds for rapid non-linear climate change (whether induced by human or natural events) which are currently unknown (Houghton, 1998). This means that the dangerous level of GHG's may be much lower than seems likely from projections based on Integrated Assessment Models. Thus a need for early action, on the precautionary basis embodied in the FCCC, is evident.

Complex non-linear dynamics also characterizes the process of technological change, so that energy sector transformations which are technologically quite easy to envisage, and quite low cost on a 'bottom up' analysis, may nevertheless fail to come about as the result of policy measures which might superficially appear adequate. 'Lock-in' of inefficient technology is familiar from the QWERTY story[2] and managerial myopia can be a contributing factor. This may present a barrier to entry for sustainable technology in the energy sector, given the powerful position of fossil fuel based incumbent firms[3].

With lock-in, costs are not exogenously determined, but depend upon initial events such as the direction of research and development, and upon learning by doing related to the cumulated experience with specific technologies. Such *path dependency* means that the question whether renewable energy or fossil fuels appear more costly in two decades time depends on the technological trajectory taken over the intervening period. Newer technology costs decline faster that for mature technologies, but overtaking may not happen, and renewable energy technology remain restricted to niche markets – with fossil fuel 'locked-in' – unless the incumbent technologies are sufficiently discouraged by effective measures to drive the change-over.

Consequently, 'a level playing field' is not an adequate basis for securing a radical energy sector technology transformation – still less for driving the rapid pace of change that is needed on a precautionary basis. Neither, even in pursuit of the modest Kyoto Protocol first commitment period target, does a level playing field deliver a least cost outcome in so far as it "elicits activities that cost up to but do not exceed the market value of permits" (MfE, 1999, p42). This is so even though much current economic orthodoxy..” (Arrow, in foreword to Arthur, 1994). “Nonconvexities and positive feedback mechanisms are now central to modern theorizing in international trade theory, growth theory, the economics of technology, industrial organization, macroeconomics, regional economics, economic development and political economy” (Arthur, 1994). But so far the dynamic implications of learning in relation to technological change have not been extended into the field of environmental policy.

This is surprising, since it was noted a quarter of a century ago that “in the long run, the development and widespread adoption of new technologies can greatly ameliorate what, in the short run, sometimes appear to be overwhelming conflicts between economic well-being and environmental quality” (Kneese and Schultz, 1975). The need for environmental economics to catch up was voiced at the May 1999 IEA/USDoE meeting on “Technologies to Reduce Greenhouse Gas Emissions”, in a call for the work of the Santa Fe Institute to be reflected in Climate Change policy-making. This paper represents an initial exercise in that direction.

In brief, the intuition is that the price paid for abatement innovations (the marginal cost of abatement) generally needs to be set higher than the market value of permits. This is because learning by doing yields a positive inter-temporal externality, whereas nothing is learned from the consumer pain of doing without[4]. Thus future abatement is lower cost on account of current abatement and it is worthwhile to invest more now in abatement innovations, in order to secure a return later in the form of lower abatement costs. It may be noted that this is a dynamic efficiency result under period-by-period perfectly competitive equilibria. It remains for investigation how much more steeply, if at all, the ‘playing field’ may need to be sloped to counter managerial myopia and other informational and industrial organization problems involved in the ‘lock-in’ phenomenon.

Optimal dynamic policy

A simple dynamic model may be set up as follows

Net Emissions = energy demanded – abatement (where we assume units chosen so that energy and emissions are co-mensurate)

$$E = D - A$$

$D = (D_0 \exp gt)(1 - k_1\tau)$ where D_0 is b.a.u. demand at the beginning of policy, g is the rate of exponential growth of demand for energy services, k_1 is the initial slope of the demand

To represent learning by doing with abatement technologies we have k_2 increasing with accumulated abatement

$k_2 = k_3 f(AA)$ where AA is accumulated abatement and the functional form f(..) follows the technology diffusion literature, representing the “progress ratio” according to which types of technologies display a characteristic proportionate cost reduction with each doubling of AA

Expressions may be written for the welfare cost of policy (CP) represented by the area of the ‘Harberger’ triangles under the abatement supply and energy demand curves. Then the objective of policy may be stated as the minimization of the aggregate discounted policy cost, DPC, subject to the path for net emissions being constrained to meet the Kyoto Protocol commitment.

$\text{Min} \quad DCP = \Sigma\, CP\exp(-\rho t)$ s.t. $E(t) = E^*(t)$, with ρ the exogenously determined discount rate

This is a simple dynamic optimization exercise which may be solved using a non-linear dynamic programming package under the GAMS software system. The coding for this model is at Appendix 2

Results

The following cases were computed, each on the basis M constrained to 1 (i.e. conventional price signaling) and M free to take the cost minimizing value.

A 2012 policy horizon, emissions constrained *ad hoc* along a path similar to that proposed officially (MfE, 1999, p).

B 2012 policy horizon, aggregate emissions between 2008 and 2012 constrained to five times the 1990 level, emissions path determined endogenously.

C 2022 policy horizon, second and third commitment period aggregate emissions constrained to a linear extrapolation of the 2000-2010 trend in B.

Table 1 (r = 0)

Year Case	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
A (2002 – 2012 emissions constrained along a linear path; PB > 0 from 2003)											
A	0.039	0.075	0.108	0.142	0.177	0.213	0.251	0.290	0.330	0.371	0.414
Q	0.815	0.839	0.860	0.882	0.905	0.929	0.955	0.982	1.010	1.039	1.070
NE	0.776	0.764	0.752	0.740	0.728	0.716	0.704	0.692	0.680	0.668	0.656
B	*0.067*	*0.119*	*0.154*	*0.182*	*0.205*	*0.226*	*0.244*	*0.261*	*0.277*	*0.291*	*0.306*
M	20.690	4.459	2.171	1.659	1.424	1.286	1.193	1.125	1.074	1.033	**1.000**
TAW	0.003	0.027	0.071	0.110	0.144	0.176	0.205	0.232	0.258	0.282	0.306
PB	0.000	0.013	0.044	0.071	0.094	0.115	0.134	0.152	0.169	0.185	0.200
M=1 (conventional price signal)											
NE	0.776	0.764	0.752	0.740	0.728	0.716	0.704	0.692	0.680	0.668	0.656
B and τ	0.050	0.097	0.137	0.170	0.197	0.221	0.242	0.261	0.278	0.294	0.309
PB	0.039	0.074	0.103	0.126	0.144	0.158	0.170	0.180	0.189	0.196	0.203
B (2008 – 2012 aggregate emissions constrained as per Kyoto commitment PB > 0 from 2008)											
A	0.056	0.059	0.061	0.063	0.065	0.067	0.287	0.311	0.329	0.344	0.357
Q	0.815	0.844	0.874	0.905	0.937	0.971	0.936	0.970	1.004	1.040	1.077
NE	0.759	0.785	0.813	0.842	0.872	0.904	0.649	0.659	0.675	0.696	0.720
B	0.094	0.091	0.087	0.085	0.083	*0.081*	*0.332*	0.313	0.299	0.288	0.279
M	14.601	14.349	14.253	14.260	14.340	14.476	1.188	1.120	1.071	1.032	**1.000**
TAW	0.006	0.006	0.006	0.006	0.006	0.006	0.279	0.279	0.279	0.279	0.279
PB	0.000	0.000	0.000	0.000	0.000	0.000	0.166	0.174	0.182	0.191	0.201
M=1 (conventional price signal)											
NE	0.752	0.779	0.807	0.837	0.868	0.900	0.651	0.660	0.675	0.695	0.719
B and τ	0.080	0.077	0.075	0.073	0.071	0.069	0.328	0.313	0.301	0.292	0.284
PB	0.060	0.060	0.061	0.061	0.062	0.062	0.214	0.206	0.203	0.203	0.204
C (2008 – 2022 aggregate emissions constrained in 3 five-year commitment periods; PB >0 in 2008)											
A	0.103	0.113	0.121	0.127	0.132	0.136	0.320	0.337	0.352	0.365	0.376
Q	0.812	0.840	0.871	0.902	0.934	0.967	0.959	0.993	1.029	1.065	1.103
NE	0.708	0.727	0.750	0.775	0.802	0.831	0.640	0.656	0.677	0.701	0.727
B	***0.175***	0.164	0.156	0.150	0.145	*0.141*	*0.313*	0.300	0.289	0.281	0.273
M	7.857	7.423	7.211	7.111	7.080	7.094	1.659	1.588	1.532	1.487	1.448
TAW	0.022	0.022	0.022	0.021	0.020	0.020	0.189	0.189	0.189	0.189	0.189
PB	0.000	0.000	0.000	0.000	0.000	0.000	0.081	0.086	0.092	0.099	0.106
M=1 (conventional price signal)											
NE	0.697	0.717	0.741	0.767	0.795	0.825	0.639	0.656	0.677	0.701	0.728
B and τ	0.150	0.143	0.138	0.133	0.129	0.125	0.298	0.287	0.279	0.271	0.265
PB	0.105	0.103	0.102	0.102	0.102	0.103	0.191	0.188	0.188	0.190	0.193
D (2008 – 2042 aggregate emissions constrained in 7 five-year commitment periods; PB >0 in 2016)											
A	0.185	0.215	0.235	0.250	0.263	0.274	0.352	0.365	0.376	0.386	0.396
Q	0.801	0.830	0.859	0.890	0.922	0.956	0.981	1.017	1.054	1.092	1.132
NE	0.616	0.615	0.624	0.640	0.659	0.682	0.629	0.652	0.678	0.706	0.736
B	***0.313***	0.285	0.267	0.254	0.245	*0.237*	*0.287*	0.279	0.272	0.266	0.261
M	4.329	3.862	3.657	3.556	3.508	3.493	2.789	2.788	2.802	2.826	2.859
TAW	0.072	0.074	0.073	0.072	0.070	0.068	0.103	0.100	0.097	0.094	0.091
PB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
M=1 (conventional price signal)											
NE	0.594	0.595	0.607	0.623	0.644	0.668	0.626	0.651	0.678	0.707	0.738
B and τ	0.280	0.262	0.249	0.239	0.230	0.223	0.263	0.256	0.250	0.244	0.239
PB	0.166	0.156	0.151	0.149	0.148	0.149	0.165	0.167	0.169	0.173	0.176
E (2008 – 2022 aggregate emissions constrained to total for 3 commitment periods; PB >0 in 2022)											
A	0.112	0.124	0.132	0.139	0.145	0.150	0.451	0.483	0.509	0.530	0.549
Q	0.811	0.840	0.870	0.901	0.933	0.966	0.929	0.962	0.996	1.032	1.068

Table 2 (r = .05)

Year Case	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2022
A (2002 – 2012 emissions constrained along a linear path; PB > 0 from 2003)											
A	0.039	0.072	0.105	0.139	0.175	0.212	0.250	0.289	0.330	0.371	0.413
Q	0.815	0.836	0.857	0.879	0.903	0.928	0.954	0.981	1.010	1.039	1.069
NE	0.776	0.764	0.752	0.740	0.728	0.716	0.704	0.692	0.680	0.668	0.656
B	0.067	0.114	0.150	0.180	0.204	0.225	0.244	0.261	0.277	0.292	0.306
M	20.690	2.753	1.809	1.503	1.343	1.241	1.169	1.113	1.069	1.032	1.000
TAW	0.003	0.041	0.083	0.120	0.152	0.182	0.209	0.235	0.259	0.283	0.306
PB	0.000	0.026	0.055	0.080	0.102	0.121	0.138	0.155	0.170	0.186	0.201
M = 1											
NE	0.776	0.764	0.752	0.740	0.728	0.716	0.704	0.692	0.680	0.668	0.656
B	0.050	0.097	0.137	0.170	0.197	0.221	0.242	0.261	0.278	0.294	0.309
PB	0.039	0.074	0.103	0.126	0.144	0.158	0.170	0.180	0.189	0.196	0.203
B (2008 – 2012 aggregate emissions constrained as per Kyoto commitment PB > 0 from 2008)											
A	0.041	0.045	0.048	0.052	0.057	0.061	0.256	0.291	0.325	0.358	0.391
Q	0.815	0.844	0.874	0.905	0.938	0.971	0.942	0.973	1.003	1.035	1.068
NE	0.775	0.800	0.826	0.853	0.881	0.910	0.686	0.681	0.679	0.677	0.676
B	0.069	0.070	0.071	0.073	0.075	0.077	0.309	0.306	0.306	0.308	0.312
M	19.972	18.954	18.072	17.291	16.589	15.950	1.210	1.137	1.081	1.037	1.000
TAW	0.003	0.004	0.004	0.004	0.005	0.005	0.256	0.269	0.283	0.297	0.312
PB	0.000	0.000	0.000	0.000	0.000	0.000	0.162	0.172	0.184	0.197	0.211
M = 1											
NE	0.770	0.795	0.822	0.849	0.877	0.906	0.687	0.682	0.679	0.677	0.675
B	0.058	0.059	0.061	0.062	0.064	0.065	0.305	0.304	0.307	0.311	0.317
PB	0.045	0.047	0.050	0.053	0.056	0.059	0.209	0.207	0.208	0.211	0.214
C (2008 – 2022 aggregate emissions constrained in 3 five-year commitment periods; PB >0 in 2008)											
A	0.065	0.072	0.079	0.087	0.094	0.102	0.277	0.310	0.342	0.374	0.407
Q	0.814	0.843	0.873	0.904	0.936	0.969	0.957	0.989	1.021	1.054	1.089
NE	0.750	0.771	0.794	0.817	0.842	0.867	0.680	0.679	0.679	0.680	0.681
B	0.110	0.110	0.110	0.112	0.114	0.116	0.299	0.299	0.301	0.305	0.310
M	12.582	11.699	11.001	10.421	9.923	9.486	1.525	1.448	1.387	1.337	1.294
TAW	0.009	0.009	0.010	0.011	0.011	0.012	0.196	0.206	0.217	0.228	0.240
PB	0.000	0.000	0.000	0.000	0.000	0.000	0.105	0.111	0.119	0.126	0.135
M = 1											
NE	0.742	0.764	0.787	0.811	0.836	0.862	0.679	0.679	0.679	0.681	0.682
B	0.093	0.094	0.095	0.097	0.099	0.101	0.287	0.289	0.292	0.298	0.304
PB	0.069	0.072	0.075	0.079	0.083	0.087	0.195	0.196	0.199	0.203	0.207
D (2008 – 2042 aggregate emissions constrained in 7 five-year commitment periods; PB >0 in 2008)											
A	0.084	0.095	0.106	0.117	0.127	0.138	0.292	0.323	0.354	0.386	0.419
Q	0.813	0.842	0.871	0.902	0.934	0.967	0.968	1.001	1.034	1.069	1.104
NE	0.729	0.746	0.765	0.786	0.807	0.829	0.676	0.678	0.680	0.682	0.684
B	0.143	0.141	0.141	0.143	0.145	0.147	0.293	0.294	0.298	0.303	0.309
M	9.636	8.818	8.213	7.732	7.331	6.985	1.915	1.830	1.761	1.703	1.652
TAW	0.015	0.016	0.017	0.018	0.020	0.021	0.153	0.161	0.169	0.178	0.187
PB	0.000	0.000	0.000	0.000	0.000	0.000	0.063	0.066	0.069	0.073	0.077
M = 1											
NE	0.719	0.737	0.757	0.778	0.800	0.822	0.674	0.677	0.680	0.683	0.686
B	0.123	0.123	0.124	0.126	0.128	0.131	0.275	0.278	0.282	0.288	0.294
PB	0.088	0.091	0.094	0.098	0.102	0.107	0.185	0.188	0.192	0.196	0.202
E (2008 – 2022 aggregate emissions constrained to total for 3 commitment periods; PB >0 in 2008)											
A	0.066	0.074	0.081	0.089	0.097	0.105	0.298	0.334	0.369	0.404	0.440
Q	0.814	0.843	0.873	0.904	0.936	0.969	0.952	0.983	1.015	1.048	1.082
NE	0.748	0.769	0.791	0.815	0.839	0.864	0.655	0.650	0.646	0.644	0.641

Table 3 (r = .10)

Year Case	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2022
A (2002 – 2012 emissions constrained along a linear path; PB > 0 from 2002)											
A	0.039	0.070	0.103	0.138	0.174	0.211	0.249	0.289	0.329	0.371	0.413
Q	0.815	0.834	0.855	0.878	0.902	0.927	0.953	0.981	1.009	1.039	1.069
NE	0.776	0.764	0.752	0.740	0.728	0.716	0.704	0.692	0.680	0.668	0.656
B	0.065	0.111	0.148	0.178	0.203	0.225	0.244	0.261	0.277	0. 292	0.306
M	9.094	2.104	1.595	1.396	1.282	1.206	1.148	1.103	1.064	1.030	1.000
TAW	0.007	0.053	0.093	0.128	0.158	0.187	0.213	0.237	0.261	0.284	0.306
PB	0.003	0.036	0.064	0.087	0.108	0.125	0.142	0.157	0.172	0.186	0.201
M = 1											
NE	0.776	0.764	0.752	0.740	0.728	0.716	0.704	0.692	0.680	0.668	0.656
B	0.050	0.097	0.137	0.170	0.197	0.221	0.242	0.261	0.278	0.294	0.309
PB	0.039	0.074	0.103	0.126	0.144	0.158	0.170	0.180	0.189	0.196	0.203
B (2008 – 2012 aggregate emissions constrained as per Kyoto commitment PB > 0 from 2008)											
A	0.029	0.033	0.038	0.043	0.048	0.055	0.228	0.272	0.319	0.370	0.427
Q	0.815	0.844	0.875	0.906	0.938	0.971	0.948	0.976	1.003	1.030	1.058
NE	0.786	0.811	0.837	0.863	0.889	0.916	0.720	0.704	0.684	0.661	0.631
B	0.050	0.054	0.058	0.062	0.067	0.072	0.287	0.297	0.311	0.327	0.347
M	16.663	17.606	18.059	18.669	19.374	17.736	1.233	1.154	1.093	1.043	1.000
TAW	0.003	0.003	0.003	0.003	0.003	0.004	0.233	0.257	0.284	0.314	0.347
PB	0.001	0.001	0.001	0.000	0.000	0.000	0.155	0.170	0.186	0.202	0.219
M = 1											
NE	0.783	0.808	0.833	0.860	0.886	0.913	0.721	0.704	0.685	0.660	0.630
B	0.042	0.045	0.048	0.052	0.056	0.060	0.281	0.294	0.311	0.330	0.352
PB	0.033	0.036	0.040	0.045	0.050	0.055	0.202	0.207	0.213	0.218	0.222
C (2008 – 2022 aggregate emissions constrained in 3 five-year commitment periods; PB >0 in 2008)											
A	0.041	0.047	0.054	0.062	0.070	0.080	0.241	0.284	0.331	0.383	0.440
Q	0.815	0.844	0.874	0.905	0.937	0.970	0.958	0.987	1.016	1.045	1.074
NE	0.774	0.797	0.820	0.843	0.867	0.890	0.717	0.702	0.685	0.662	0.634
B	0.070	0.075	0.080	0.085	0.091	0.098	0.282	0.294	0.309	0.327	0.347
M	19.674	17.783	16.124	14.655	13.346	12.173	1.453	1.371	1.305	1.249	1.201
TAW	0.004	0.004	0.005	0.006	0.007	0.008	0.194	0.214	0.237	0.262	0.289
PB	0.000	0.000	0.000	0.000	0.000	0.000	0.118	0.128	0.138	0.148	0.158
M = 1											
NE	0.769	0.792	0.815	0.839	0.862	0.886	0.716	0.702	0.685	0.663	0.635
B	0.059	0.063	0.068	0.073	0.078	0.084	0.270	0.285	0.302	0.321	0.343
PB	0.045	0.050	0.055	0.061	0.067	0.074	0.194	0.200	0.207	0.213	0.218
D (2008 – 2042 aggregate emissions constrained in 7 five-year commitment periods; PB >0 in 2008)											
A	0.046	0.053	0.061	0.070	0.079	0.090	0.246	0.289	0.336	0.388	0.445
Q	0.815	0.844	0.874	0.905	0.937	0.970	0.962	0.991	1.021	1.051	1.081
NE	0.769	0.791	0.813	0.835	0.857	0.879	0.715	0.702	0.685	0.663	0.635
B	0.078	0.083	0.089	0.095	0.101	0.108	0.280	0.293	0.308	0.327	0.347
M	17.586	15.831	14.310	12.976	11.795	10.743	1.563	1.479	1.410	1.351	1.300
TAW	0.004	0.005	0.006	0.007	0.009	0.010	0.179	0.198	0.219	0.242	0.267
PB	0.000	0.000	0.000	0.000	0.000	0.000	0.103	0.111	0.120	0.127	0.134
M =	1										
NE	0.763	0.785	0.807	0.830	0.852	0.875	0.714	0.701	0.685	0.663	0.636
B	0.066	0.071	0.076	0.081	0.087	0.093	0.266	0.281	0.298	0.318	0.340
PB	0.051	0.056	0.061	0.067	0.074	0.082	0.190	0.197	0.204	0.211	0.216
E (2008 – 2022 aggregate emissions constrained to total for 3 commitment periods; PB >0 in 2008)											
A	0.037	0.042	0.047	0.054	0.061	0.069	0.189	0.220	0.255	0.294	0.337
Q	0.816	0.844	0.874	0.905	0.937	0.971	0.971	1.001	1.032	1.064	1.096
NE	0.779	0.803	0.827	0.851	0.876	0.901	0.782	0.781	0.777	0.770	0.759

Several unsurprising results emerge from these tabulations, most easily apparent from the zero discounting case in Table 1, as follows:

1. Where a commitment is to be met over several time periods, and the revenue from taxation is greater than is needed to finance the optimum pattern of abatement (i.e. the potential ‘pork barrel PB’ is greater than zero) then the effective (discounted) tax is the same in each time period (underlined parts of some rows in table 1). This is because, by assumption, there are no inter-temporal externalities from doing without and deadweight losses are minimized by equalizing the marginal disbenefit between periods.
2. At the time horizon for policy, when no future benefits from inter-temporal externalities can be taken into account, the simple comparative static result applies and $b=\tau$, as with conventional price signals (shown bold in table 1).
3. Because there are future benefits from learning by doing with abatement, and because learning by doing occurs in each period in which abatement activity arises, it is always optimal to pay a higher (discounted) price for abatement in earlier periods. This leads to a progressive decrease in the marginal cost of abatement B (save for transitions between commitment periods, shown in italics in table 1).
4. Before a commitment applies, there is no benefit from raising prices higher than is necessary to cover the cost of abatement (there is an implicit assumption that firms will not borrow in order to finance abatement and that the policy is self-financing, with firms raising prices to consumers). No benefit arises from unnecessary consumer pain. This zero ‘pork barrel’ phase is equivalent to simple PAO.
5. When a commitment applies it may or may not become necessary to raise prices more than is needed to finance the optimal level of abatement, but a phase of mixed PAO/price signals (both PB > 0 and M > 1) occurs before the final time period of pure price signalling.
6. The longer the time horizon (assuming continuing intensification of policy commitments) the more early abatement it is worthwhile to undertake (shown bold italics in Table 1).
7. For a given time horizon, the efficient policy for an aggregate target over the whole time horizon involves more early abatement than the (overall more costly) policy which is efficient in a succession of separate commitment periods (shown underlined bold italics in Table 1).

Conclusions

Two significant results have emerged from the simple model:

1. The optimal (least cost) path involves an *initially high value for M, falling over time*.
2. At the time horizon for policy, M falls to 1 because there are no dynamic gains from learning by doing when policy is indifferent to future events. If the model is optimized over a longer time horizon, M remains above zero throughout the first commitment period. Thus *a concern for future policy costs involves investing in abatement technologies at a greater rate during*

more complex model will be developed further, taking account of the effects of policy ‘leakage’ and of secondary costs in the macroeconomy (‘top down’ effects).

This paper, and the extensions just proposed, are, as noted earlier, dynamic only in the limited sense of incorporating learning by doing in a succession of period by period perfectly competitive equilibria. Obviously the market for energy cannot accommodate both environmentally sustainable energy technologies and the continued growth of fossil fuel technology along the trend post world war 2. As a major and eventually dominant role emerges for sustainable energy, investment in, research on and development of fossil fuel technologies will be discouraged and slacken and the historic decline in fossil fuel costs be reversed[5]. Thus the impact of the determined expansion of sustainable energy technologies through the implementation of dynamically effective policy instruments could see a more rapid shift in relative costs than results just from learning. Effectively this implies that the long run production possibility frontier is concave, reflecting the path dependency of competing technologies, rather than convex like the familiar text-book representation of a world of diminishing returns. Such a shift in the technological pattern would influence managerial expectations, leading possibly to a band-wagon collapse of the barriers to entry that arise from managerial myopia. Obviously there is a wealth of research problems to be tackled.

References

Table 2 (r = .05)

<u>Year</u>	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
<u>Case</u>											
A (2002 – 2012 emissions constrained along a linear path)											
B (2008 – 2012 aggregate emissions constrained as per Kyoto commitment)											
C (2008 – 2022 aggregate emissions constrained in 3 successive 5 year commitment periods)											
D (2008 – 2042 aggregate emissions constrained in 7 successive 5 year commitment periods)											
E (2008 – 2022 aggregate emissions constrained overall to total for 3 commitment periods)											
F (2008 – 2042 aggregate emissions constrained overall to total for 7 commitment periods)											

Table 3 (r = .10)

<u>Year</u>	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
<u>Case</u>											
A (2002 – 2012 emissions constrained along a linear path)											

Appendix 1

Allocating Permits Usefully (APU)

A variety of proposals for ‘complementary measures’ was advanced at the recent Toronto Conference on Domestic Emissions Trading[6] (DET – e.g.for Canada, Australia, Denmark, New Zealand, USA, UK,). These were motivated by the need to provide incentives for emissions reducing innovations ‘downstream’, i.e. beyond the ‘point of obligation’ of an ‘upstream’ permit-based DET scheme. In general, the measures are an administrative mess, proposed only because of the high transactions cost of a downstream scheme.

Also, the initial allocation of permits was widely recognized at the Toronto meeting to be problematic. Proposals canvassed involved either auctioning (seen by industry as, effectively, an objectionable tax) or ‘grand-fathering’ (seen by consumers as a political ‘pork barrel’). Either of these allocations waste the opportunity to use the allocation mechanism constructively, for reducing the costs of policy to the minimum, as required by the least cost principle embedded in the FCCC.

That this has escaped attention is because of a widespread belief that price signals – carbon taxes or equivalent tradeable emissions permit schemes – are efficient, i.e. yielding the least cost achievement of the policy commitment to a quantified emissions limitation and reduction objective. However, this belief is based on a static general equilibrium analysis (Baumol and Oates, 1988) that neglects the phenomenon of learning-by-doing, and which has been shown to fail when such dynamic effects are taken into account[7].

Dynamically efficient policy requires initial investment in a more rapid pace of early-action abatement than results from conventional price signaling. Learning-by-doing with abatement technologies then yields a beneficial externality that provides a return on the initial investment through lower costs of abatement during the later stages of policy development (when more stringent commitments, and consequently a large volume of abatement activity, are to be expected). This investment in early learning-by-doing can be stimulated by putting an initially higher price on abatement relative to the effective tax on emissions.

Note that permit trading does not in itself reduce emissions (although limitation of the quantum of permits necessarily leads to reduced emissions – save for illegal evasion and legal 'leakage' overseas). What trading the conventionally allocated limited quantum of permits serves to do is to select the least cost bundle of abatement projects, up to the trading price of permits. However, it is these abatement projects (plus the consumer pain of ‘doing without’) that actually reduces emissions.

It was agreed at Toronto that low transactions costs require an upstream point of obligation for permit trading. But upstream firms (extractors and importers of fossil fuel and large point emitters, with allocations to the latter deducted from allocations to the primary suppliers) have rather few opportunities for reducing emissions within their own businesses. Also, many of these have already been taken up in voluntary early action.

A downstream point of permit obligation raises transactions costs. Moreover, extension of permit obligations downstream still does not impact effectively on the house-builders, the vehicle producers and the landowners whose decisions determine many of the low-cost emissions abating potential innovations. If a landowner slaughters his methane emitting milk-herd for meat, and grows CO2 absorbing trees instead, there is a double benefit to emissions mitigation. But this has a negligible impact on the landowner's fuel bill. The methane uncertainty on the demand side of the energy market (the demand to emit) the emissions cap represented by a fixed quantum of emissions permits gives greater certainty of achieving the policy commitment.

One advantage of this APU proposal is that, with the permit cap rigidly fixed and delivering the Kyoto commitment, the regime for project credits can be quite relaxed. Instead of heavy-handed additionality requirements, an industry-friendly regime of light-handed measuring and monitoring that engages the goodwill of management can be envisaged. Thus there would be a leaky but effective bucket for baling out the ‘greenhouse gas boat’, rather than the perfectionist thimble of legalistic baselines, verification, etc.

However, the key point of APU is that a 'level playing field' is not dynamically efficient and is not sufficient to get over the barriers to innovation that face the dynamically efficient rate of take-up of abatement technologies. Because of learning-by-doing, there are dynamic benefits from having a high value of **M** initially. This means that permits could initially be got quite easily, in exchange for a small fraction of a project-based credit, thus providing a big incentive to overcome the barriers to new technology innovation.

To reiterate, it is proposed that emissions permits be neither auctioned nor grand-fathered but issued as the reward for downstream innovation. ***Thus permits would be issued by the government in exchange for previously generated and certified project-based credits, either purchased in the market for abatement credits, or initiated directly by the small number of firms at the upstream point of obligation. The number of permits issued would be a multiple, M, of the number of credits surrendered, with M initially large and decreasing over time.*** If the credits available from prior action are too few – or are kept off the market in anticipation of higher value under future policy tightening – the government could sell ‘back-door’ credits at a premium, spending the resulting ‘safety valve’ revenue on projects.

The advantages of this allocation arrangement are that it:–

- rewards early action without prejudice to the integrity of the overall emissions cap;
- resolves the political problem of choosing between allocation by grand-fathering or by auction;
- creates a separate market for project-related credit-based trading, with upstream firms as buyers;
- resolves the problem of reconciling project-based credit trading with a permit-based emissions cap without prejudice to the integrity of the cap, thus providing an ‘un-messy’ complementary measure;
- ameliorates the price rise related problems of policy leakage and loss of competitivity;
- can be simply adjusted, by varying the quantum of emissions permits, to keep capped emissions ‘on track’ towards the 2008-12, and later, lower, commitments;
- is administratively simple (save for the transactions costs of project-related measuring and monitoring which are inevitable given participation in the Kyoto flexibility mechanisms);
- facilitates a regime for measuring and monitoring projects that can be industry-friendly and light- handed, and hence with low transactions costs, and without the intrusive informational demands created by strict additionality;
- can drive innovation, by varying **M**, to secure least discounted aggregate policy cost, taking advantage of expected rates of cost reduction from learning-by-doing with new technologies; and
- provides the flexibility which may be needed in relation to particular types of innovation, which can be boosted by receiving a higher than general **M** – e.g. if a particular technology is path-dependent for an important later technology (say producing bio-fuel raw material before committing to costly plant for

Appendix 2

Coding for 2012 time horizon

```
$ONTEXT

$TITLE OPTIMAL ABATEMENT WITH LEARNING BY DOING
$OFFUPPER
$OFFSYMLIST
$OFFSYMXREF
SETS      T  time periods /2001 * 2012/
          TFIRST(T) first year
          TLAST(T) last year;

          TFIRST(T) = YES$(ORD (T) EQ 1);
          TLAST(T)  = YES$(ORD (T) EQ CARD(T));
          DISPLAY TFIRST, TLAST;
ALIAS (T,S);


SCALARS
E90 emissions in 1990 /  .68     /
E01 emissions in 2001 / .788    /
K0 demand choke price for carbon services /4.2/
K1 initial slope of demand curve / .197  /
K2 unused  /9999/
K3 initial slope of abatement supply / .591  /
K4 progress ration for abatement technology / .32   /
A02 initial experience with abatement technologies /.162/
C constant cost of emissions and carbon supply   / .2 /
G gowth rate of final demand for energy services /0.035 /
RHO discount rate /0.0/
H end of history policy begins next period /1/;

PARAMETERS    DISC(T) discount factor
              GROWTH(T) growth factor
              ECAP(T) emissions cap;
DISC(T) = EXP(-RHO*ORD(T));
GROWTH(T) = EXP(G*(ORD(T)-1));
ECAP(T) =  E01- (E01-E90)*(ORD(T)-1)/9  ;


VARIABLES
A(T)            abatement quantity
AA(T)           cumulated A up till T-1
B(T)            marginal abatement cost
PC(T)           in period cost
```

```
EXPERIENCE(T)       cumulated abatement
ABATE(T)            abatement increasing with experience
DEMAND (T)          demand for carbon
NETEMIT(T)          demand minus abatement equals capped emissions
COSTA(T)            policy cost in year AGAIN
DISCOST             aggregate discounted cost of policy (objective function)
DISCOST12           THE SAME TO 2012
PORKY(T)            porkbarrel - make it a positive variable avoids fundit eqn
marcosta(T)         MARGINAL COST OF ABATEMENT
smoothit(t)         stop the output jumping about to help initial convergence
mfe(t)              mfe proposal in DPOS discussion paper
kyoto               five year constraint
KYOTO2              TEN YEAR CONSTRAINT
KYOTO3              FIFTEEN YEAR CONSTRAINT;

EXPERIENCE(T) ..                 AA(T) =E= A02$(ORD(T) EQ H+1)
                                           +(AA(T-1)+A(T-1))$(ORD(T) GT H+1);
ABATE(T)$(ORD(T) GT H) ..     A(T)     =E=  K3*((AA(T)/A02)**K4)*B(T) ;
DEMAND(T)$(ORD(T) GT H) ..    Q(T)     =E=  GROWTH(T)*K1*(K0 - C - TAW(T))  ;
PORKY(T)$(ORD(T) GT H) ..     PB(T)    =E=  TAW(T)*Q(T) - B(T)*A(T);
NETEMIT(T)$(ORD(T) GT H) ..   NE(T)    =E=  Q(T) - A(T) ;
MARCOSTA(T)$(ORD(T) GT H) ..  B(T)     =E=  N(T)*TAW(T);
smoothit(t)$(ORD(T) GT H+1) ..n(t)     =g= .5*n(t-1);
COSTA(T)$(ORD(T) GT H) ..      PC(T)   =E=
                            0.5*(A(T)*B(T)+K1*GROWTH(T)*(TAW(T)**2)) ;
DISCOST..       DPC    =E=  SUM(T$(ORD(T) GT H), PC(T)*DISC(T));
DISCOST12..     DPC12  =E=  SUM(T$(ORD(T) GT H), PC(T)*DISC(T))
                            -SUM(T$(ORD(T) GT 12), PC(T)*DISC(T));
mfe(T)$(ORD(T) GT H) ..       NE(T)    =E= ECAP(t) ;
kyoto ..  sum(t$(ord(t) GT (h+6)), NE(t)-ECAP(t)) -
                            sum(t$(ord(t) GT (h+11)), NE(t)-ECAP(t)) =L= 0;

MODEL  ZERO    / EXPERIENCE, ABATE,  DEMAND,   NETEMIT,  COSTA, PORKY,
                MARCOSTA, smoothit,  DISCOST, DISCOST12 ,mfe   /;
SOLVE ZERO USING NLP MINIMIZING DPC ;
DISPLAY AA.L, A.L, B.L,  TAW.L, Q.L, N.L, PB.L, NE.L, PC.L, DPC.L, DPC12.L ;

MODEL ONE / EXPERIENCE, ABATE,  DEMAND,   NETEMIT,  COSTA, PORKY,
                MARCOSTA, DISCOST, DISCOST12 , mfe  /;
SOLVE ONE USING NLP MINIMIZING DPC ;
DISPLAY AA.L, A.L, B.L,  TAW.L, Q.L, N.L, PB.L, NE.L, PC.L, DPC.L, DPC12.L ;

MODEL TWO / EXPERIENCE, ABATE,  DEMAND,   NETEMIT,  COSTA, PORKY,
                MARCOSTA, DISCOST, DISCOST12 ,kyoto   /;
SOLVE TWO USING NLP MINIMIZING DPC ;
```