The Role of Carbon Taxes and R&D Subsidies in Climate Policy

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June 2005
International Energy Workshop
Kyoto, Japan

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Outline

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3. The model

4. Second best policy: how critical is timing?

5. Conclusion

Motivation

- Climate change problem is a long-term issue.
- Innovation and learning is now closely connection with climate policies
- Much of the existing literature ignores questions of how to combine carbon taxes with innovation subsidies within an intertemporal framework, when competing carbon-free technologies come into play.
- Present paper provides two "worked examples" illustrating how the prospect of a future carbon-free and profitable energy technology may affect climate and innovation policy.

Policy Issues

Public policies affect the prices of carbon based fuels, which in turn affect incentives to undertake research and development (R&D) aimed at bringing alternative fuels to market earlier at a lower cost and/or at a higher capacity.

Instrument choice involves choosing between technology subsidies or carbon taxes. If there are no market failures apart from the externalities connected to pollution, the cost-minimizing policy is to use carbon taxes alone as they directly target the market imperfection.

Wigley et al. (1996) examine the optimal timing of CO2 emission abatement if there is a long-term stabilization goal of atmospheric CO2 concentration. Discounted abatement costs are minimized if the bulk of abatement takes place after technology costs are lower.

Technology development involves knowledge capital which may be public, hence leading to a potential source of market failure.

New Policy Issue: Timing

Timing of climate policy has so far been concentrated to carbon taxes and emissions abatement, but timing is also relevant for a technology subsidy, in particular if we expect new technologies to be developed.

A tecnology may only be profitable for a certain period of time, and benefits of a technology may be lost with bad timing.

1. How should the optimal technology subsidy evolve over time?

2. Given that the optimal combination of taxes and subsidies over time requires a substantial degree of foresight, what is the cost of simpler policy rules or delays in policy implementation?

3. Suboptimal policy may lead to lock-in of the wrong technology, but under which conditions may lock-in be particularly important, and should we avoid subsidying existing technologies in fear of lock-in?

We do this in the context of two deterministic dynamic equilibrium models based on Manne and Barreto (2002).

- A *learning by doing* model
- A *research and development* model

The current talk focuses exclusively on the R&D model.

A Dynamic Model

Energy technologies:

Defender (def), the average type of unit on line in the year 2000; a predominantly fossil mix of technologies, but it also includes hydroelectric and nuclear; it is neither subject to LBD nor resource scarcity within the relevant time horizon;

Challenger (chl), the initial challenger – the average type of carbon-free technology available in 2005; this is high-cost but subject to learning-by-doing (LBD); and

Advanced (adv), an advanced challenger – the average type of carbon-free technology that might become available during this century; this is lower-cost and also subject to the endogenous type of learning.

The model is a conventional Ramsey formulation, in which we maximize the present value of utility over an infinite horizon:

$$\max_{C_t} \quad \left(\sum_{t=0}^{\infty} \Delta^t C_t^{\rho_T} \right)^{\frac{1}{\rho_T}}$$

subject to constraints:

1. Output in each period is either consumed, invested in physical capital or employed in research and development activities:

$$Y_t = C_t + I_t + \sum_j I_{jt}^E + \sum_j RD_{jt}$$

2. Output is produced through a nested, constant-elasticity-of-substitution production function which combines labor, capital and energy:

$$Y_t = \phi \left[\theta \left(\sum_j E_{jt} \right)^{\rho} + (1-\theta)(L_t^{\alpha} K_t^{1-\alpha})^{\rho} \right]^{1/\rho}$$

3. Energy production is a function of labor and capital inputs:

$$E_{jt} = \phi_j \left(\beta_j (K^E_{jt})^\rho + (1-\beta_j)(\lambda_{j,t} L^E_{jt})^\rho\right)^{1/\rho}$$

4. Capital accumulation

$$K_{t+1} = K_t\,(1-\delta_t) + J_t, \quad K^E_{j,t+1} = K^E_{jt}\,(1-\delta_{j,t}) + \lambda_{jt} J^E_{jt}$$

   λ_{jt} is an index of productivity for energy technology j in time period t which affects both labor and capital productivity.

5. Productivity is a function of accumulated R&D:

$$\lambda_{jt} = \frac{1+\ell_j}{1+\ell_j \left(\frac{Z_{jt}}{\overline{\overline{Y}}_j}\right)^{-\gamma}}$$

   where accumlated R&D depends on previous net investment:

$$Z_{jt+1} = Z_{jt} + \sum_{\tau<t} \Omega_{j,t-\tau} X_{j,\tau}$$

6. Labor supply

$$L_t + \sum_j L_{jt} = \overline{L}_t$$

7. Depreciation rates for both aggregate and energy capital are isoelastic in relation to the level of maintenance:

$$\delta_t = \psi\left(\frac{K_t}{M_t}\right)^{\epsilon}, \quad \delta^E_{jt} = \psi\left(\frac{K^E_{jt}}{M^E_{jt}}\right)^{\epsilon}$$

8. Net and gross investment are related through Uzawa's quadratic adjustment cost model:

$$I_t = J_t\left(1 + \phi\frac{J_t}{2K_t}\right), \quad I^E_{j,t} = J^E_{j,t}\left(1 + \phi\frac{J_{j,t}}{2K_{j,t}}\right), \quad RD_{j,t} = X_{j,t}\left(1 + \phi^E\frac{X_{j,t}}{2Y_{j,t}}\right)$$

9. Initial capital stocks and knowledge stocks are given:

$$K_0 = \overline{K}_0, \quad K^E_{j,0} = \overline{K}^E_j, \quad Y_{j0} = \overline{Y}_j$$

Key Difference between LBD and R&D Models

In all of Manne's models going back to ETA, the transition to new technologies is governed by *expansion* and *contraction* rate constraints. These inequalities serve the role of technology-specific capital stocks:

$$E_{jt}/(1+\delta) \leq E_{j,t+1} \leq E_{jt}(1+\epsilon) + \beta$$

A problem with the LP-style formulation is that expansion and contraction rates are insensitive to changes in relative prices.

Our R&D model is based on explicit capital stocks through which rates of entry and exit for energy technologies are endogenous and price-responsive.

Carbon Dioxide Emissions

Emissions are associated only with energy production by def.

Aggregate emissions are subject to a fixed upper bound:

$$\sum_t E_{\mathsf{def}_t} \leq \overline{G}$$

Implementational Issues

- Economic model (with *exogenous* productivity effects) is solved as a complenetarity problem using GAMS/MPSGE in one year time intervals over a 95 year horizon (2005 to 2100).

- R&D model is solved as a nonlinear program over a 245 year horizon:

```
objdef..               PROFIT =e= SUM((j,t), TFP(j,t) * vtfp(t,j)

                                   - plvl(t)*X(j,t)*(1 + phir(j)*X(j,t)/(2*Z(j,t))));

tfpdef(j,t)..          TFP(j,t) =e= (1+lc(j)) / (1+lc(j)*(Z(j,t)/Z0(j))**(-gamma(j)));

experience(j,t+1)..    Z(j,t) + sum(lag, omega(j,lag) * X(j,t-(ord(lag)+1))) =e= Z(j,t+1);
```

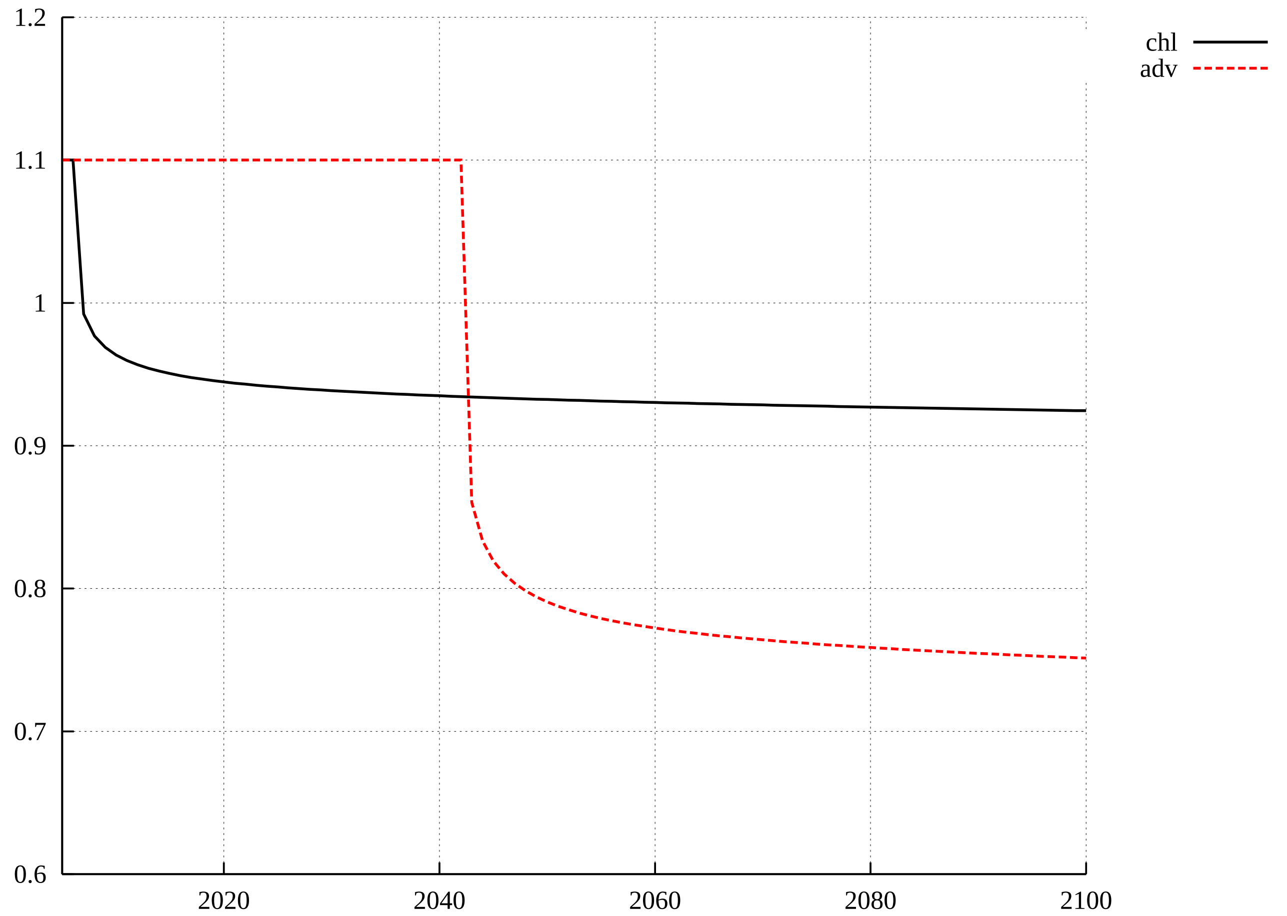
Technology Parameters:

The parameter values are strictly illustrative but not unplausbible.

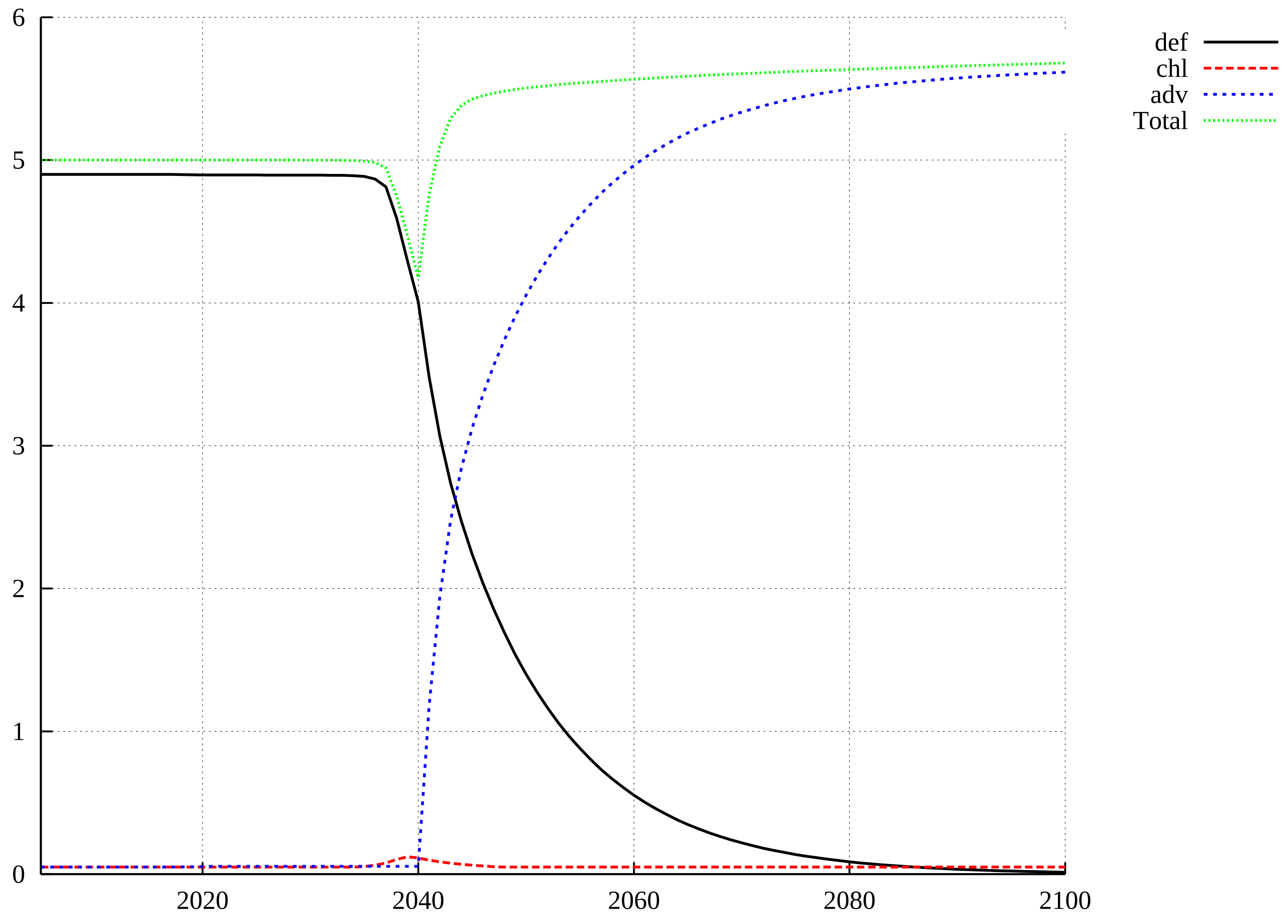
Baseline growth path is consistent with an economy growing at 2% per year, an interest rate of 5%, and a depreciation rate of 7%. The capital value share is 48%, and the energy value share if 5%.

	def	chl	adv
Static cost index, $\bar{c}_j$	1	0.9	0.7
Initial learning cost, ℓ_j,		0.2	0.4
Learning exponent, γ_j		-.2	-.2
Initial knowledge stock, $\overline{Y}_j$		0.01	0.01
Adjustment cost parameter, ϕ_j^E		0.1	0.1
First Year in which the technology is available	2005	2005	2040

Productivity Growth Paths (maximum penetration rates)



Energy Supply Paths Along the Baseline



Scenarios

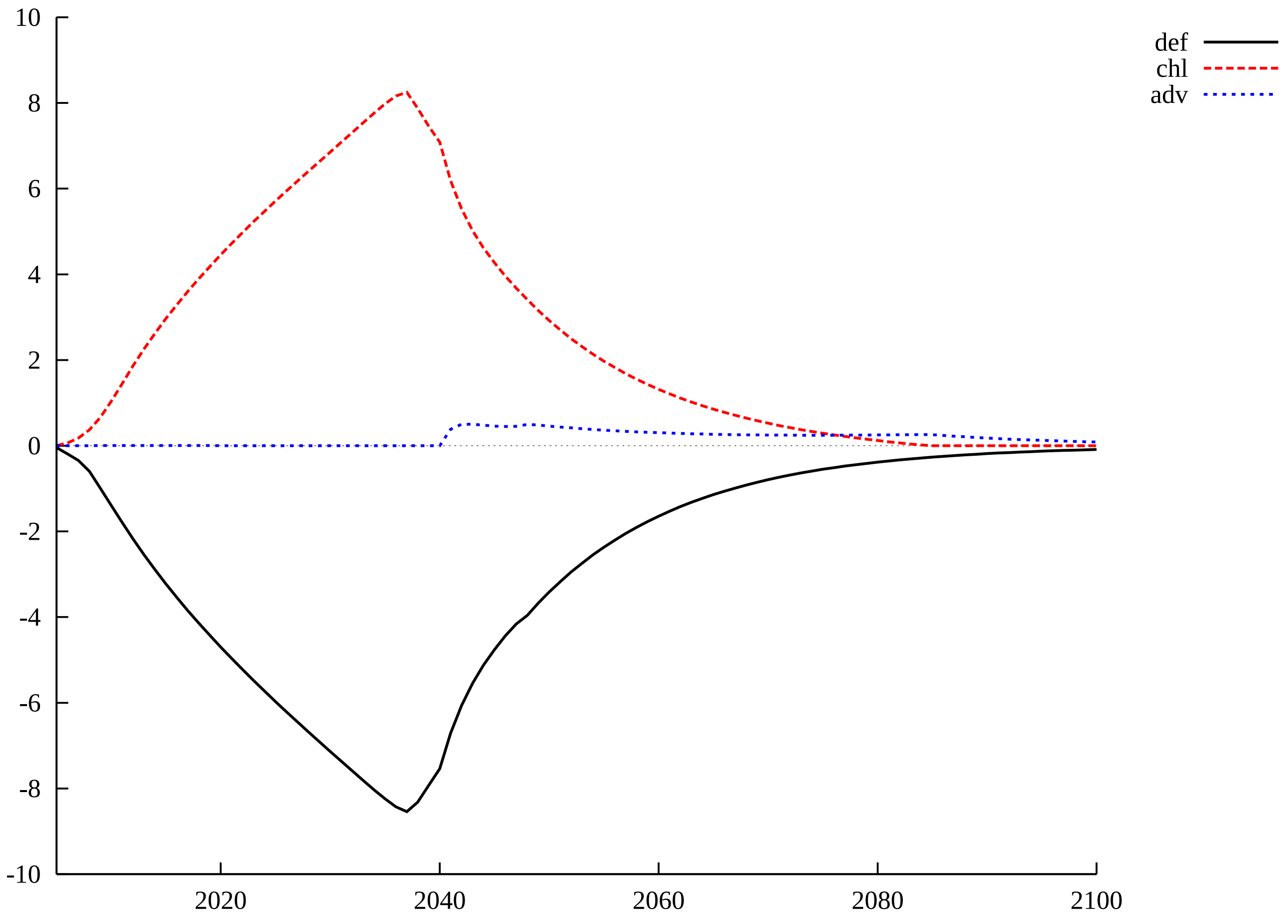
1. *Optimal* : R&D programs for both *chl* and *adv* are optimally chosen

2. *Uniform* : R&D funding for *chl* and *adv* are constrained to be equalized over the period 2005 to 2040.

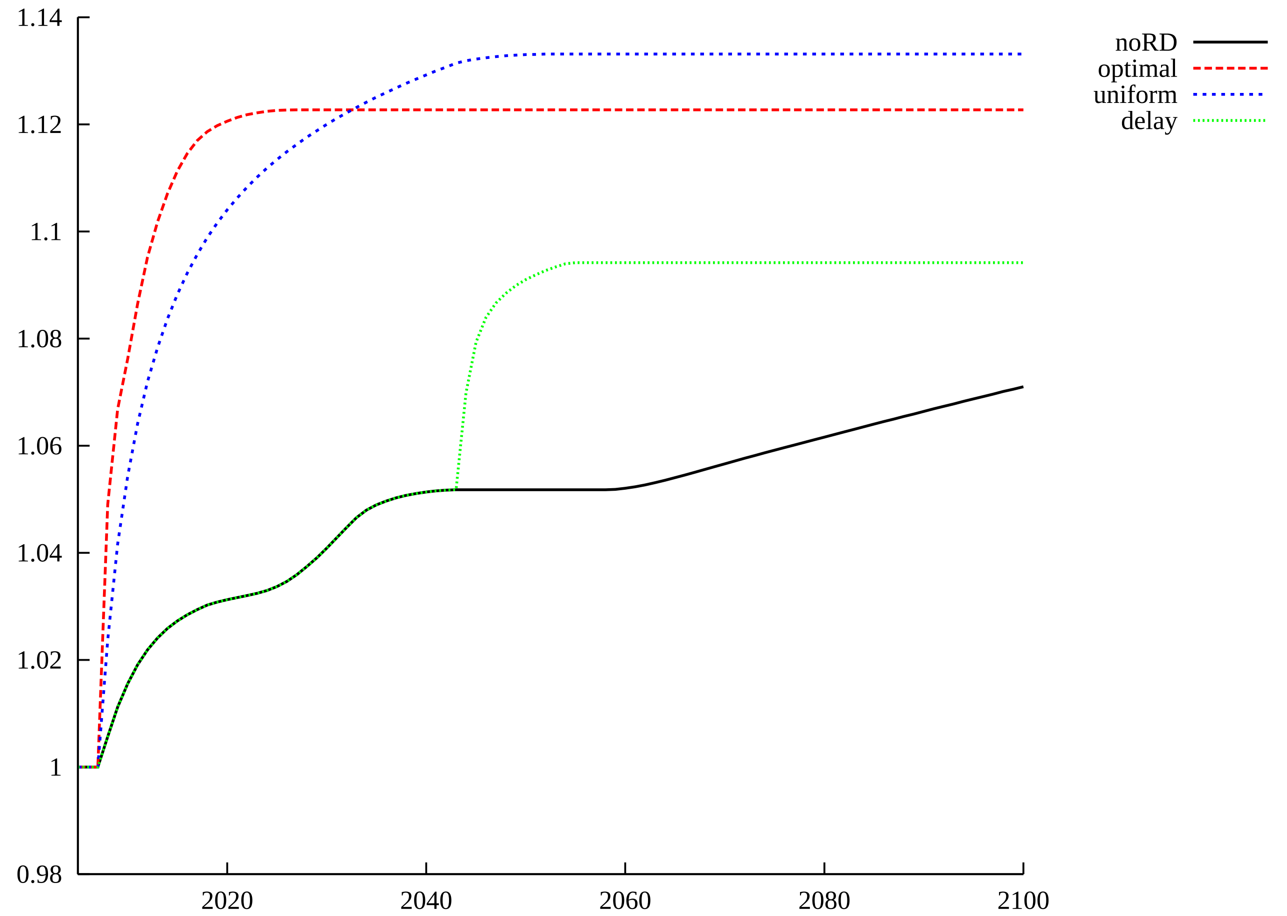
3. *Delay* : No change in R&D over the period 2005 to 2040.

4. *NoRD* : No change in energy R&D (relative to the baseline) through the model horizon.

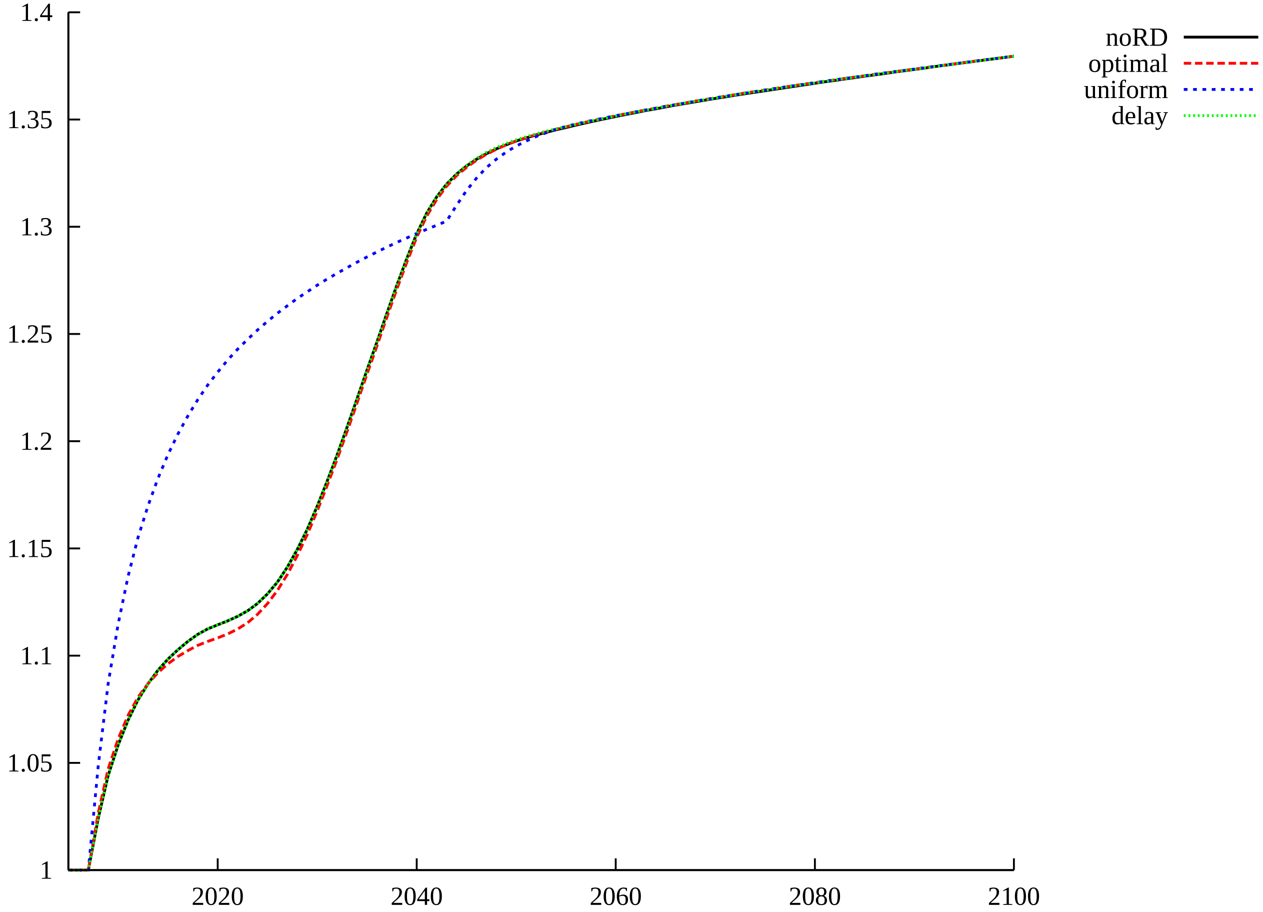
Changes in Energy Supplies with Carbon Constraint (optimal)



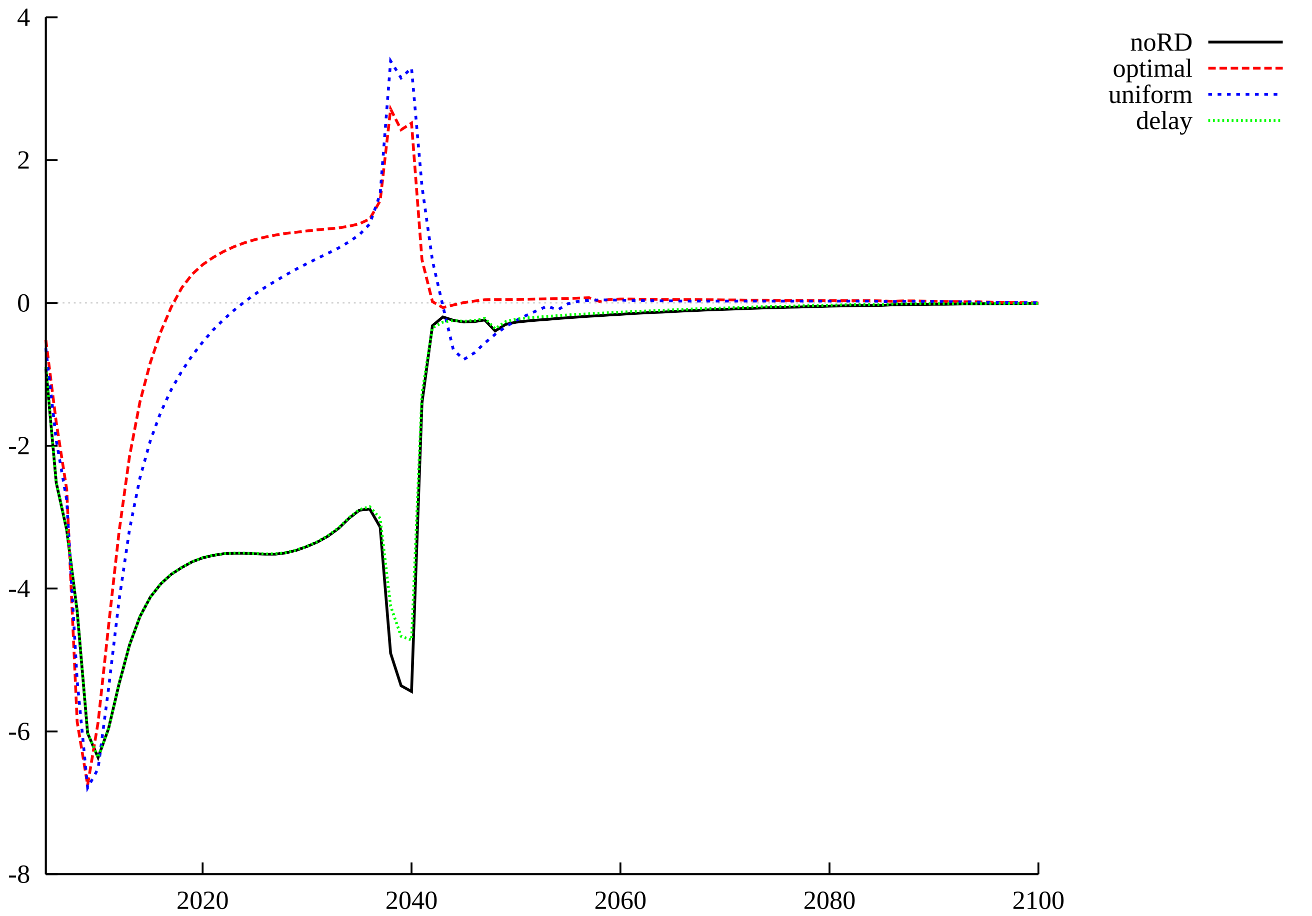
Changes in CHL Productivity



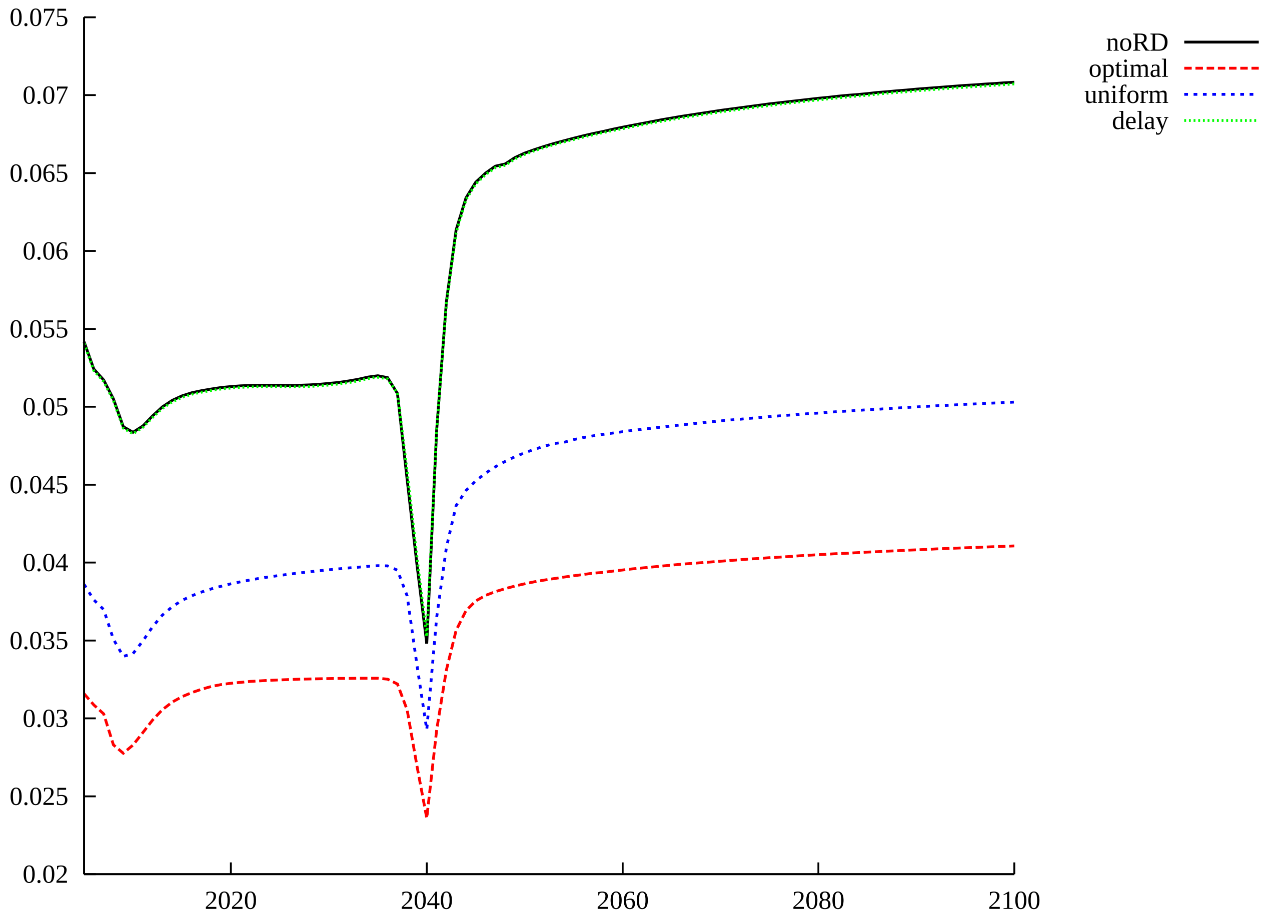
Changes in ADV Productivity



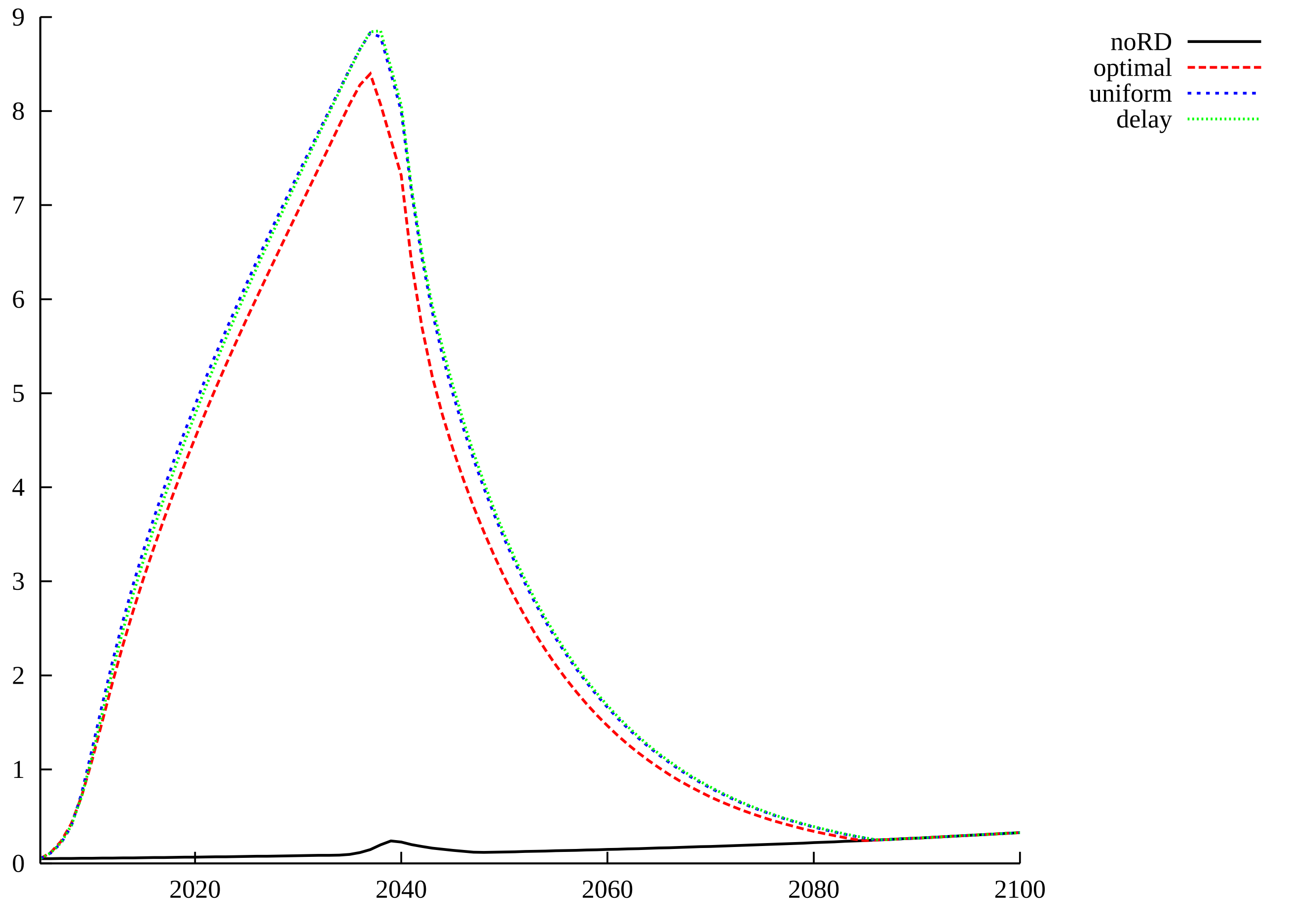
Energy Consumption (changes relative to baseline)



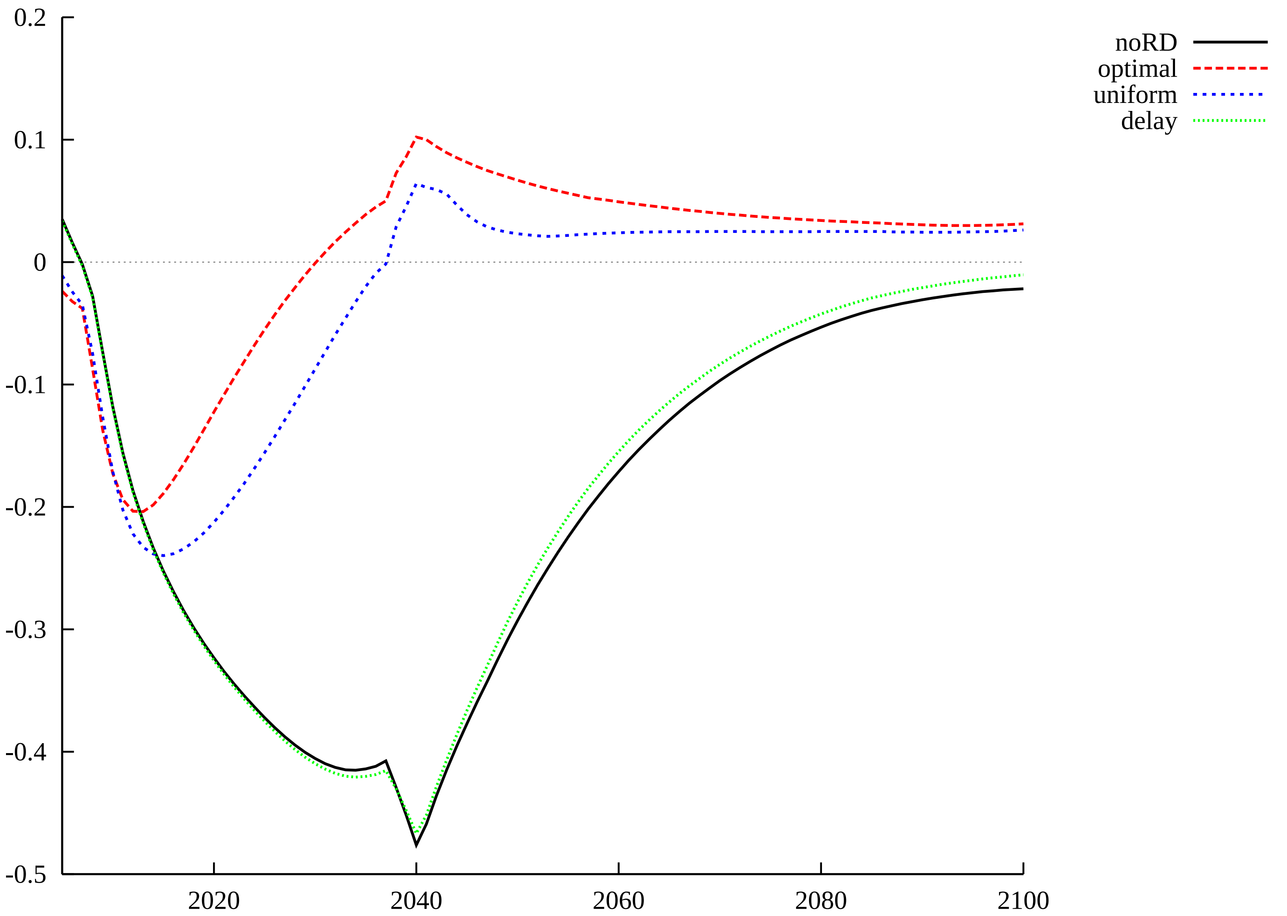
Future Value Carbon Tax Rates



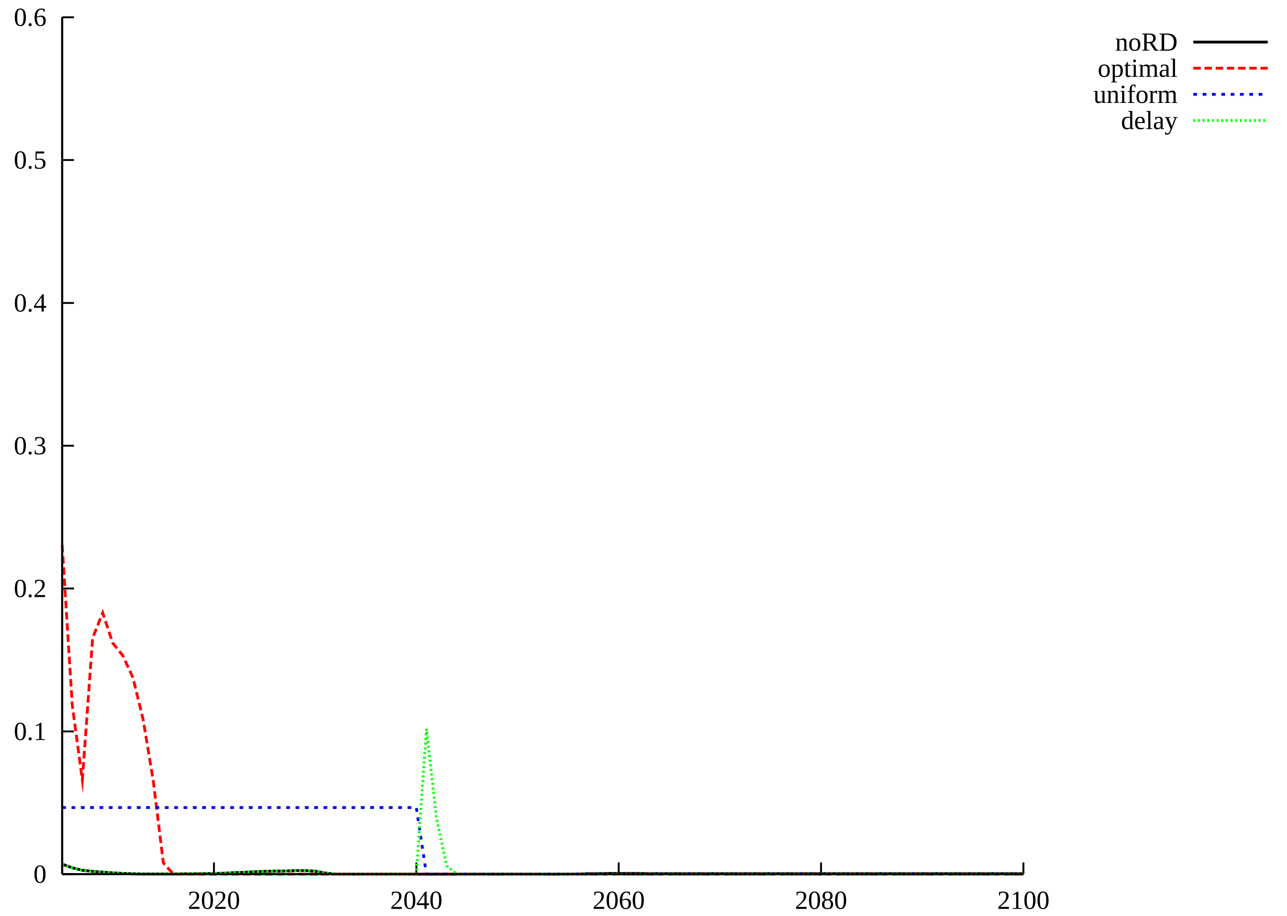
Energy Supplies by Challenger



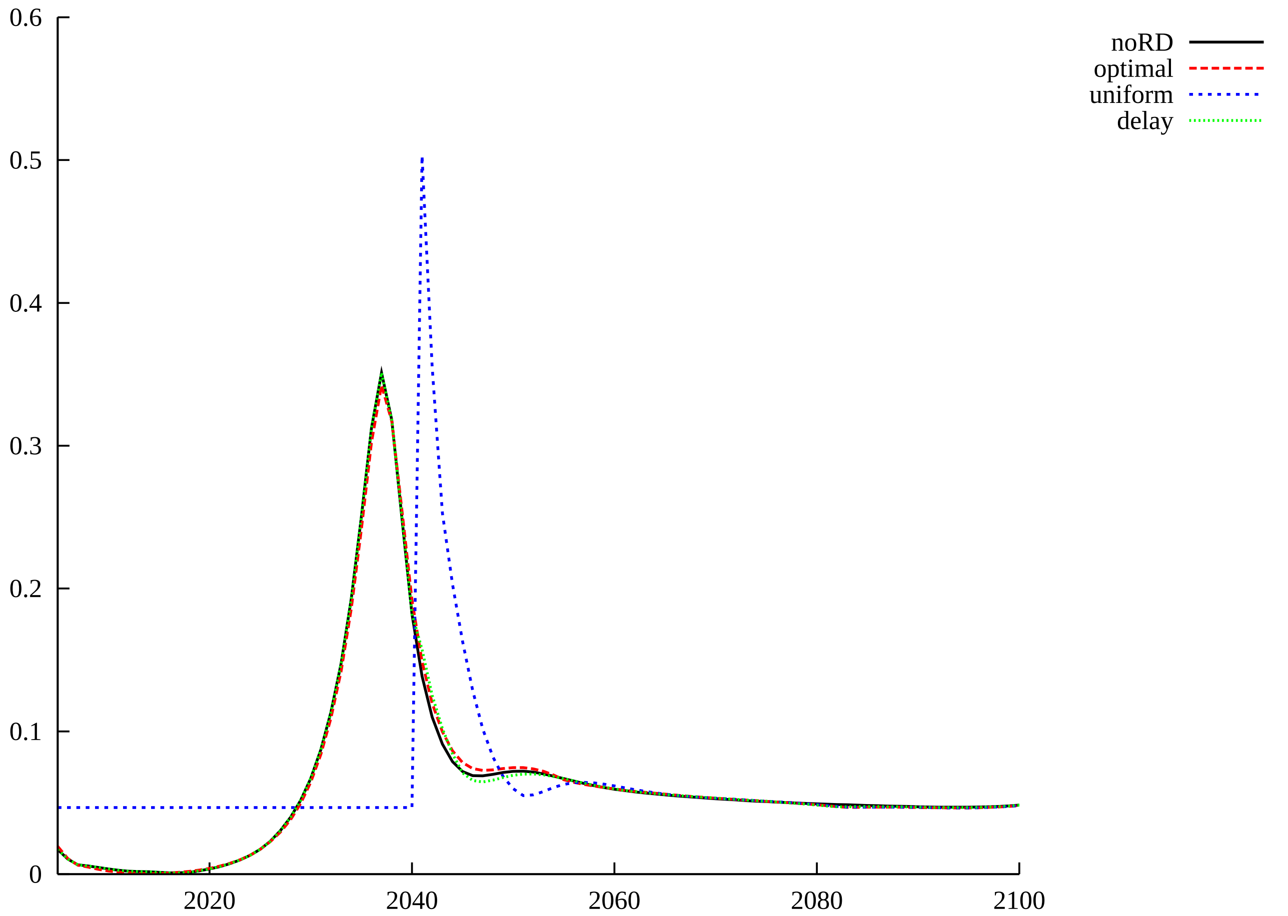
Consumption Losses



R&D Expenditures for Challenger



R&D Expenditures for Advanced



Conclusions and Directions for Further Work

Timing is an important issue in climate change, both for carbon taxes and for technology subsidies.

Simple policy rules may be nearly optimal, but we cannot judge the robustness of this finding.

Even along an optimal policy path there may be substantial transitory impacts on energy prices.

All of these issues are beset with uncertainty, both from the perspective of the social planner and from the perspective of the firm. Stochastic equilibrium models can be complex, but they may be needed to help us understand these issues.

Decomposition of economic equilibrium and R&D components of the policy model presents a promising approach to this class of problem.