Innovation, Uncertainty and Instrument Choice for Climate Policy

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Outline

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2. Policy issues

3. The model

4. First-best policy

5. Sensitivity analyses

6. Conclusion

Motivation

- Climate change in a long-term problem

- Energy sector innovation is an integral part of current climate policies

- The existing literature tends to ignore questions of how to combine carbon taxes with innovation subsidies in an intertemporal framework, when competing climate-friendly technologies come into play.

- *Uncertainty* regarding the cost and availability of alternative non-fossil energy technologies.

- The present paper provides a simple model which describes the issues and illustrates the policy challenges.

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. How does first-best subsidy and carbon tax policy measures respond to innovation.

3. How does the optimal policy trade-off between the accumulation of physical and knowledge capital stocks.

4. 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 examine these issues in the context of a stochastic equilibrium model based on Manne and Barreto (2002).

A Dynamic Model

Defender (def), the carbon-based fossil fuel mix of technologies available at low cost; it is neither subject to R&D activities nor resource scarcity within the relevant time horizon;

Challenger (chl), the carbon-free challenger technology currently available but not operated in the baseline because it is more costly than the conventional Defender; R&D activities may allow to increase productivity, i.e. reduce costs of the Challenger.

Advanced (adv), an advanced carbon-free technology that might become available during this century; this is lower-cost than Challenger and also subject to productivity changes through R&D; in the baseline – without carbon policy constraints – the Advancer is not operated.

Economic Environment

A single representative agent maximize the present value of utility over an infinite horizon:

$$\max U(C) = \sum_{t=0}^{\infty} \frac{\Delta^t \; C_t^{1-\theta}}{1-\theta}$$

subject to constraints:

1. Output is consumed (C), invested (I) to used in research (X) or employed for capital maintenance (M):

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

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

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

3. Energy based on technology j is produced through inputs of labor and capital inputs:

$$E_{jt} = \psi_j \left[\beta_j \left(K^E_{jt}\right)^\rho + (1-\beta_j)\left(\lambda_{jt} L^E_{jt}\right)^\rho\right]^{1/\rho}$$

4. Capital accumulation in aggregate production based on investment and depreciation:

$$K_{t+1} = K_t\,(1-\delta) + I_t$$

5. Capital accumulation in energy sector based on (net) investment and (endogenous) depreciation:

$$K^E_{jt+1} = K^E_{jt}\,(1-\delta_{jt}) + \lambda_{jt} J^E_{jt}$$

in which λ_{jt} is an index of energy technology j productivity in time period t which affects both labor and investment (embodied technical change)

6. Energy sector productivity is a function of accumulated R&D:

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

where accumulated R&D depends on previous net investments:

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

7. Labor supply

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

8. Depreciation rates for energy capital are an isoelastic function of the level of investment:

$$\delta^E_{jt} = \psi \left(\frac{K^E_{jt}}{M^E_{jt}} \right)^{\epsilon}$$

9. Net and gross investment in the energy sector are related through Uzawa's quadratic adjustment cost model:

$$I^E_{jt} = J^E_{jt} \left(1 + \phi \frac{J_{jt}}{2K_{jt}} \right)$$

10. The same adjustment cost model applies for knowledge capital:

$$RD_{jt} = X_{jt}\left(1 + \phi^E \frac{X_{jt}}{2Z_{jt}}\right)$$

11. Initial capital stocks (physical and knowledge) are given exogenously:

$$K_0 = \bar{K}, \quad K_{j0}^E = \bar{K}_j^E, \quad Z_{j0} = \bar{Z}_j$$

Relation to Conventional Bottom-Up Models

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

$$\frac{E_{jt}}{1+\delta} \leq E_{jt+1} \leq E_{jt}(1+\epsilon)+\beta$$

A problem with the linear programming formulation is that expansion and contraction rates are insensitive to to changes in relative prices.

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

Climate Policy Constraint

Emissions are associated only with energy production by `def`. Aggregate emissions over an 80 year horizon are subject to a fixed upper bound:

$$\sum_t E_{\mathsf{def},t} \leq \bar{G}$$

Stochastic Structure

Recourse places a central role in our model. Decisions taken in early years (2006 to 2030) hedge against uncertain future outcome. Three policy instruments: reseach and development, capital investment and carbon taxes. Investments undertaken in early years hedge against uncertainty about the availability of advanced technology in later years.

State variables in our model include both K^E_{jt} and Z_{jt}.

The date at which `adv` technology becomes available is the source of uncertainty. Early period investment decisions hedge against uncertainties, taking into account opportunities for adaptation in subsequent periods.

Stochastic Program

$$\max E\left(U(\tilde{C})\right)$$

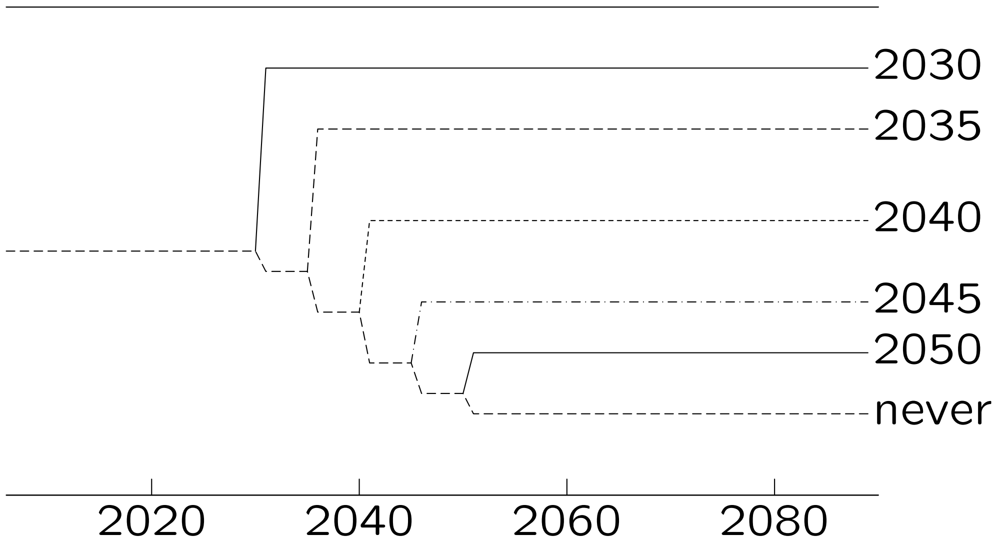
s.t.

State-contingent market constraints:

$$\tilde{Y}_{st} = \tilde{C}_{st} + \tilde{I}_{st} + \sum_j \tilde{I}^E_{jst} + \sum_j \tilde{X}_{jst} + \sum_j \tilde{M}_{jst}$$

etc.

Stochastic Structure



Model Solution

- The economic model (with *exogenous* productivity effects) is solved as a complementarity problem using GAMS/MPSGE in annual time steps over a 85 year horizon.

- Stochastic elements of the model are introduced through new tools for stochastic programming in a complementarity format (Meeraus and Rutherford, 2005).

- The R&D model is solved as a nonlinear program over a 200 year horizon:

$$\max \sum_{t=0}^{200} \quad \lambda_{jt} V_{jt} - p_t X_{jt} \left(1 + \phi \frac{X_{jt}}{2Z_{jt}}\right)$$

subject to:

$$\lambda_{jt} = \frac{1 + \ell_j}{1 + \ell_j (\frac{Z_{jt}}{\bar{Z}_j})^{-\gamma}}$$

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

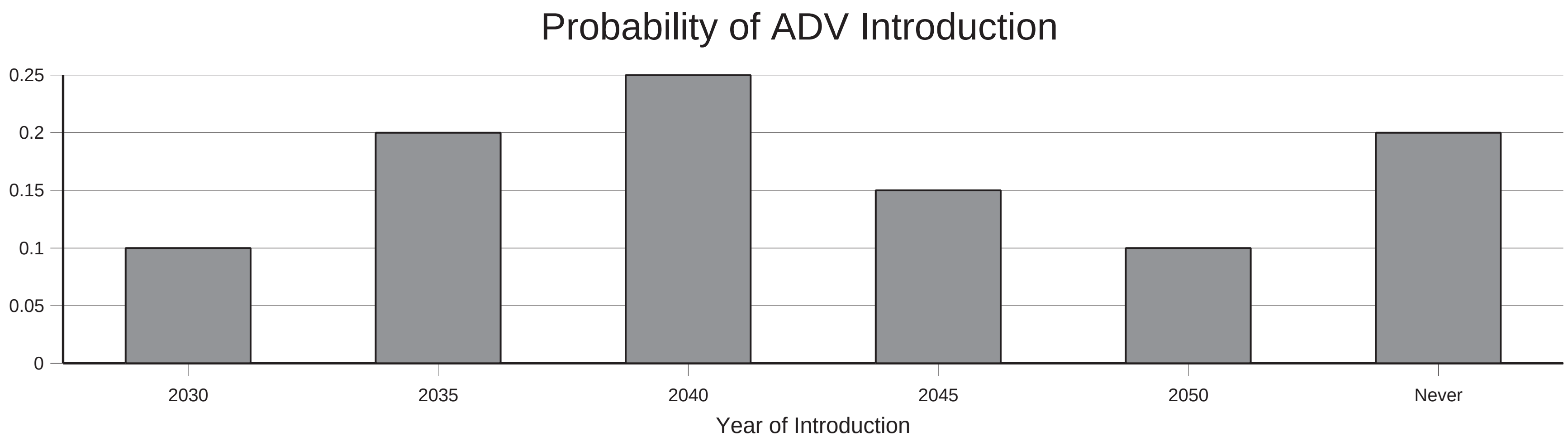
$$Z_{j0} = \bar{Z}_j$$

Technology Parameters

Parameter values are assumed for illustration.

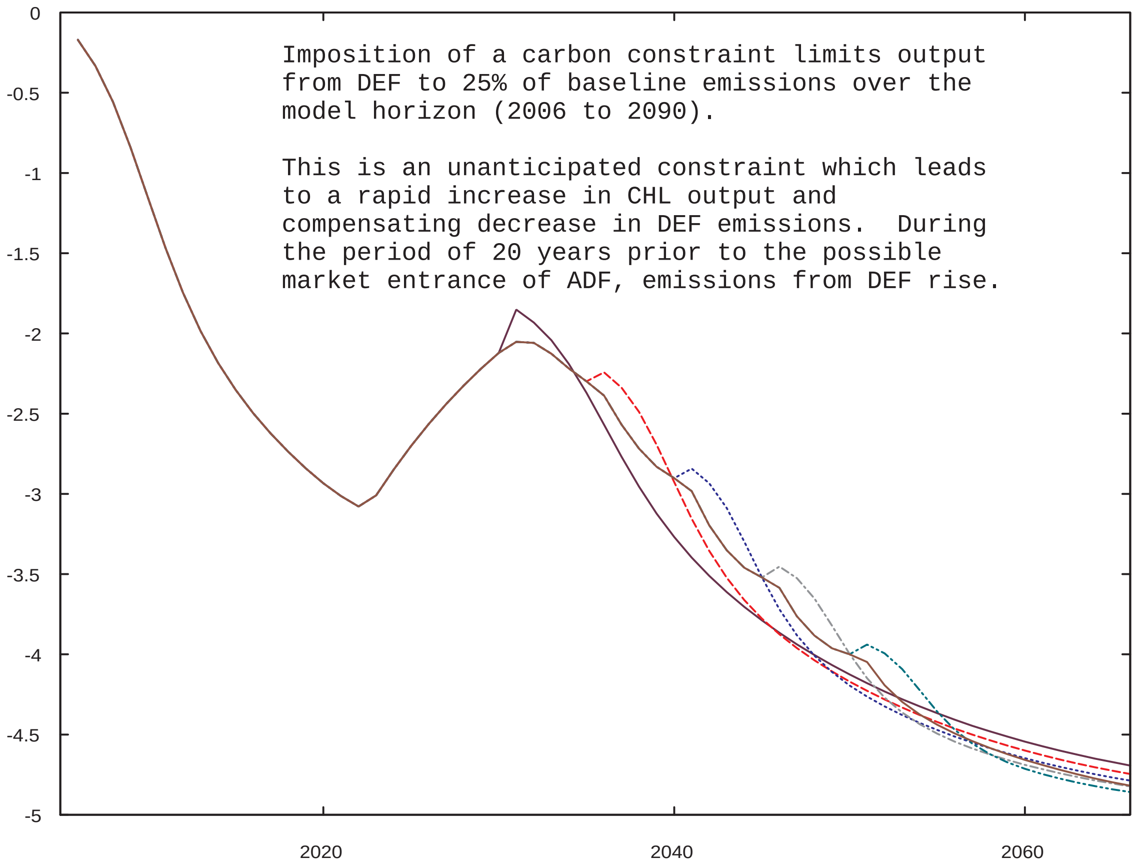
Baseline growth rate for the economy is 2% per year, the baseline energy value share is 5%, and the net interest rate 5%. The depreciation rate is 7% in macro production and 5% in the energy sector.

	def	chl	adv
Long-Run Cost	1	1.5	1.1
Entry Cost	1	2	1.5
Adjustment Cost Parameter	0	0.5	0.5
Learning Exponent	0	0.2	0.2
Availability	current	current	2030 or later

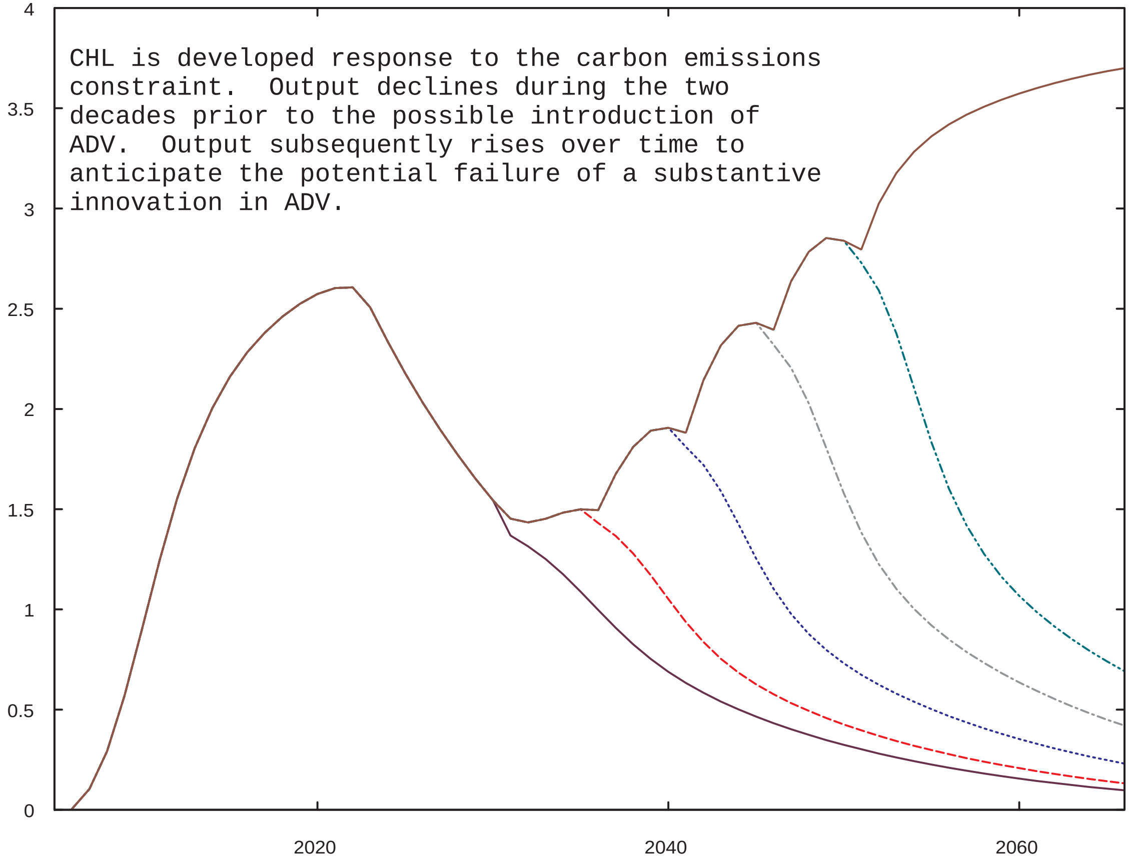


Probability of ADV Introduction
0.25
0.2
0.15
0.1
0.05
0
2030
2035
2040
2045
2050
Never
Year of Introduction

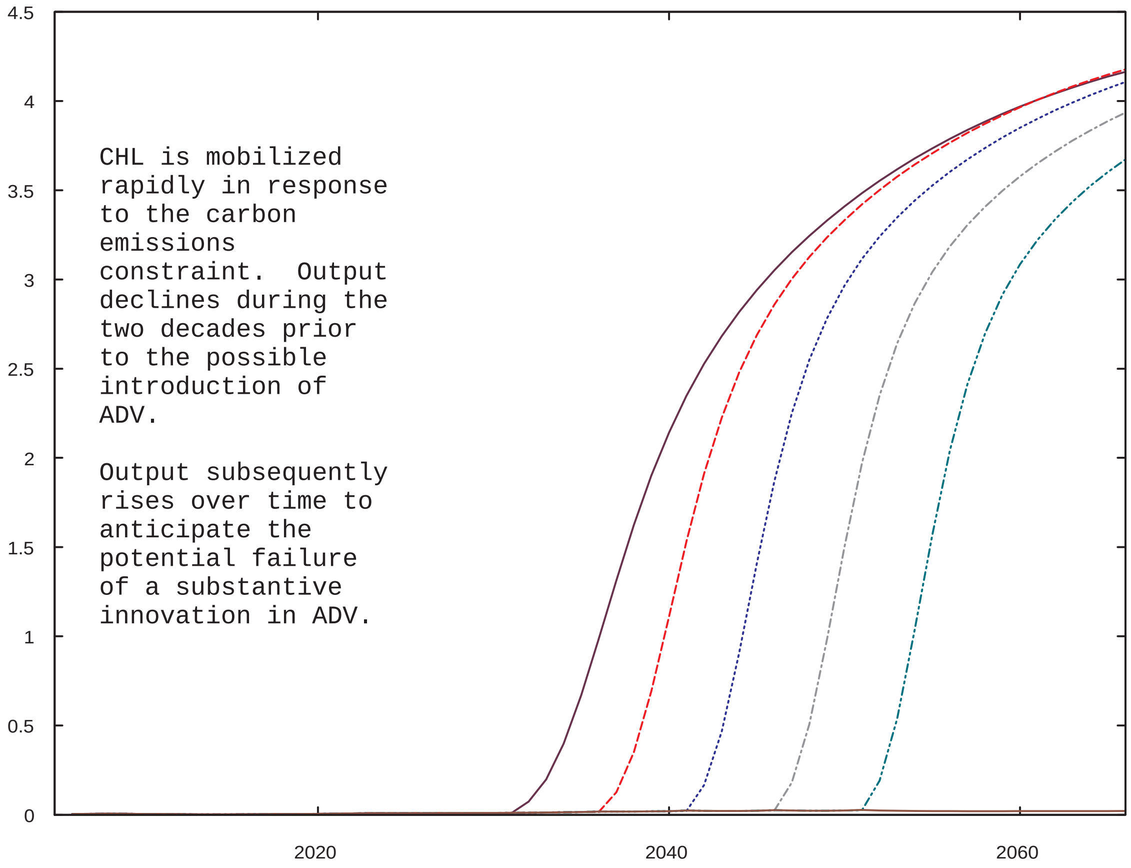
Defender Output



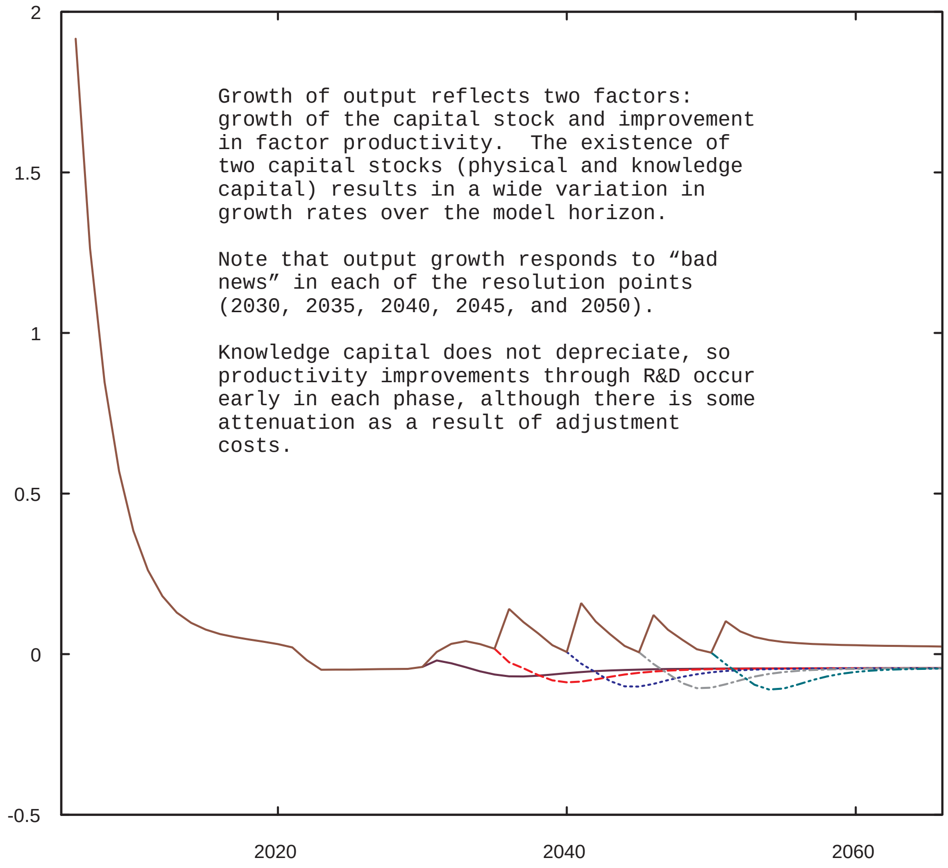
Challenger Output



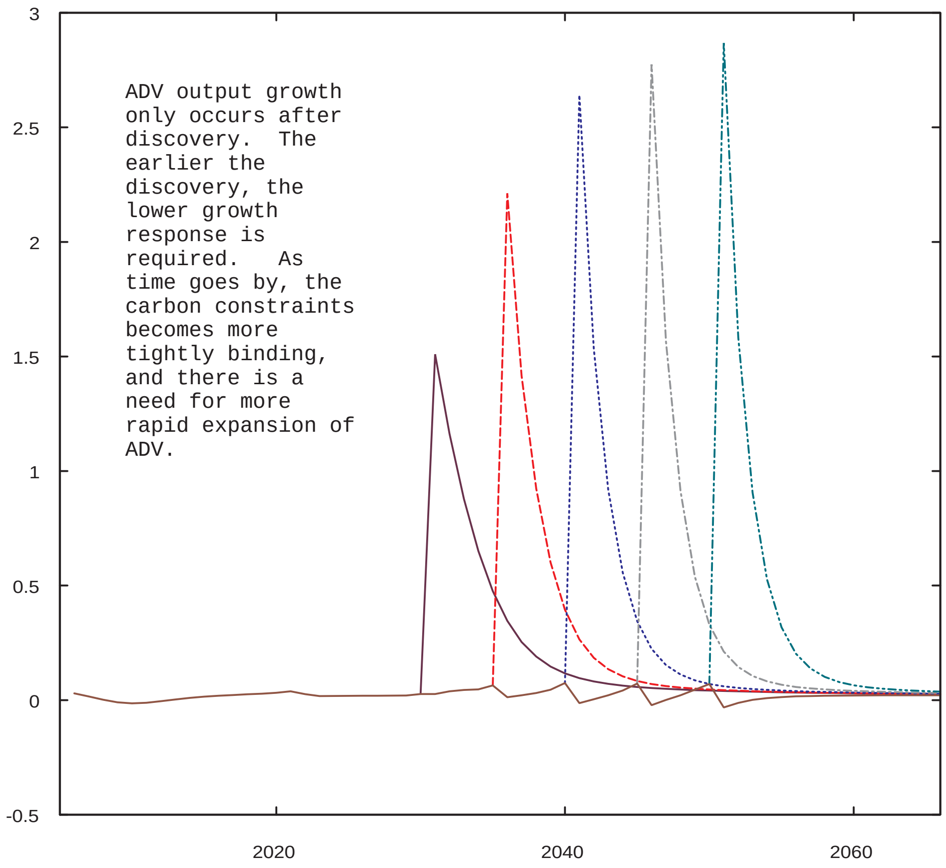
Advanced Output



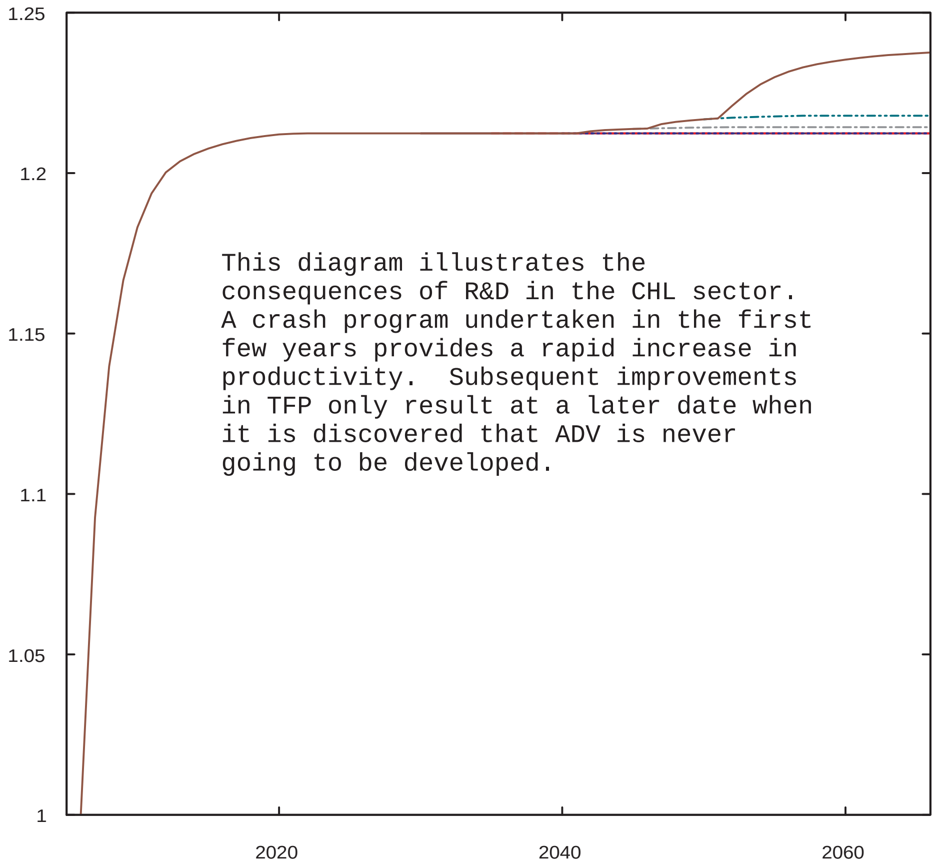
Growth Rate in CHL Output



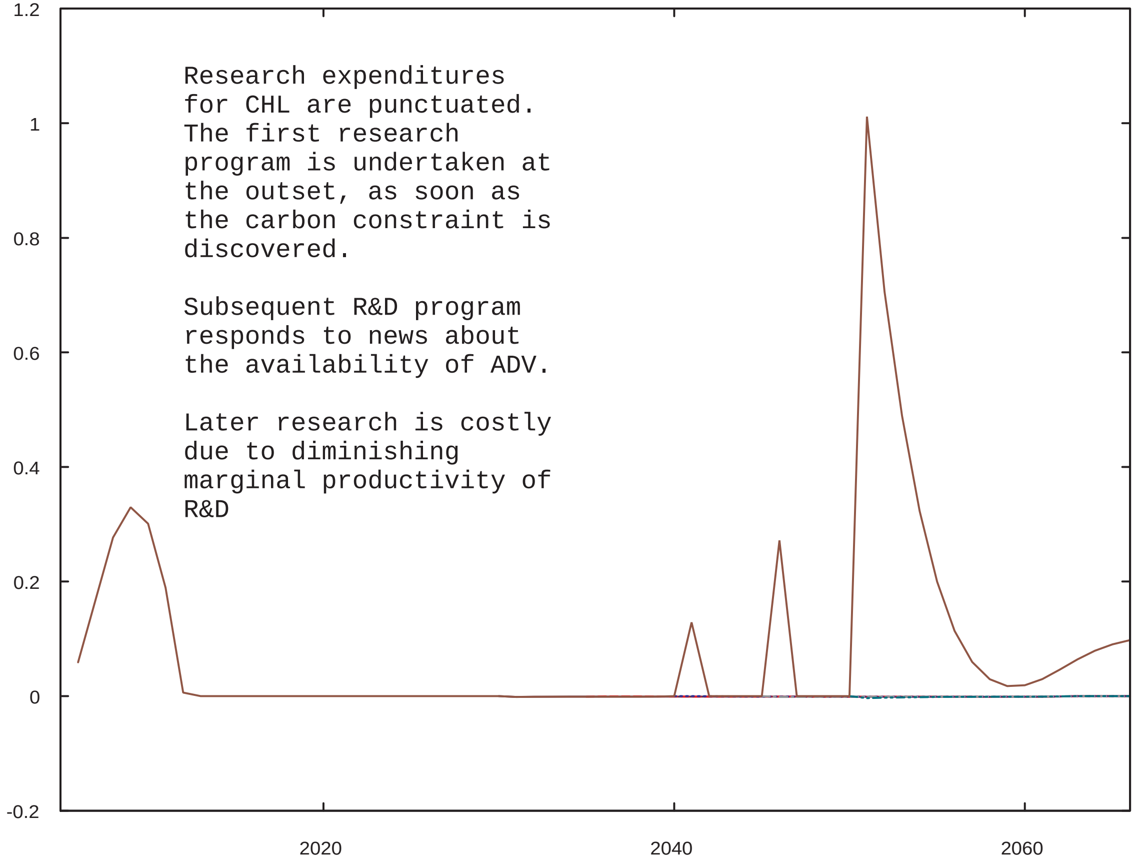
Growth Rate in ADV Output



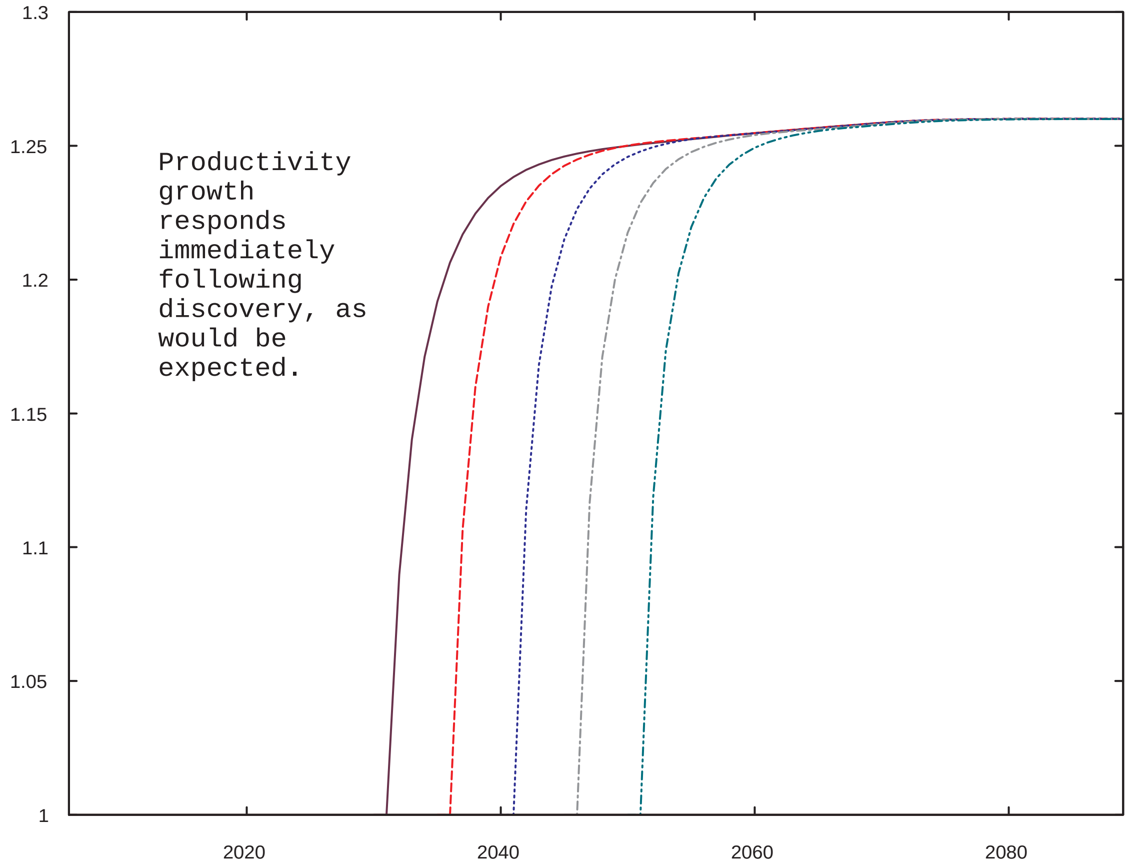
CHL Factor Productivity



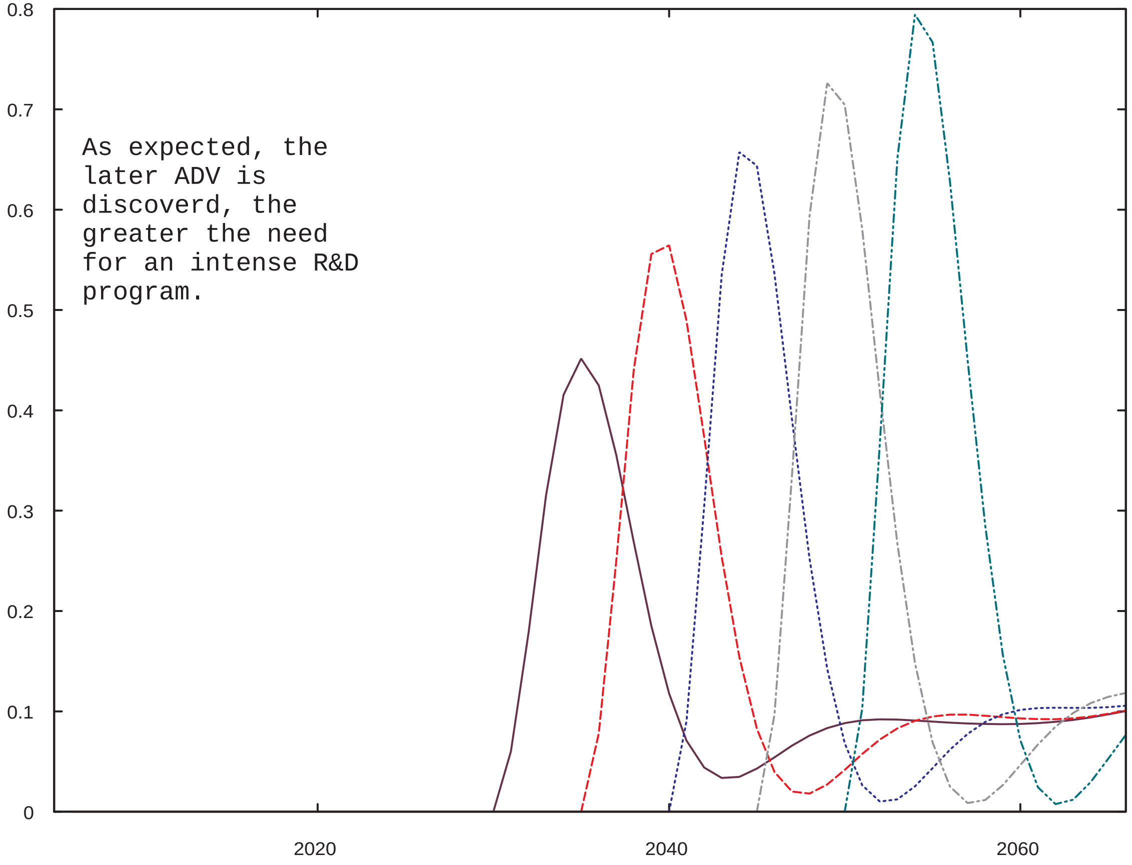
CHL R&D Expenditure



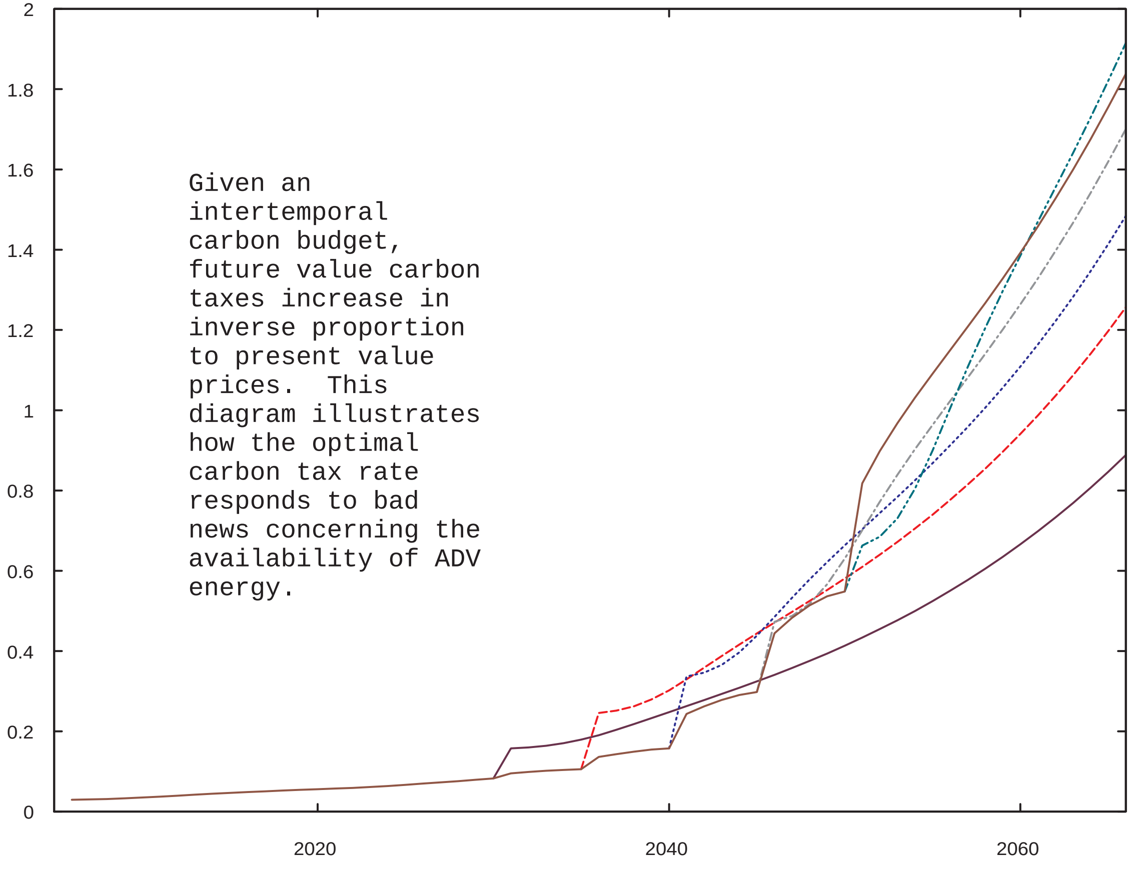
ADV Factor Productivity



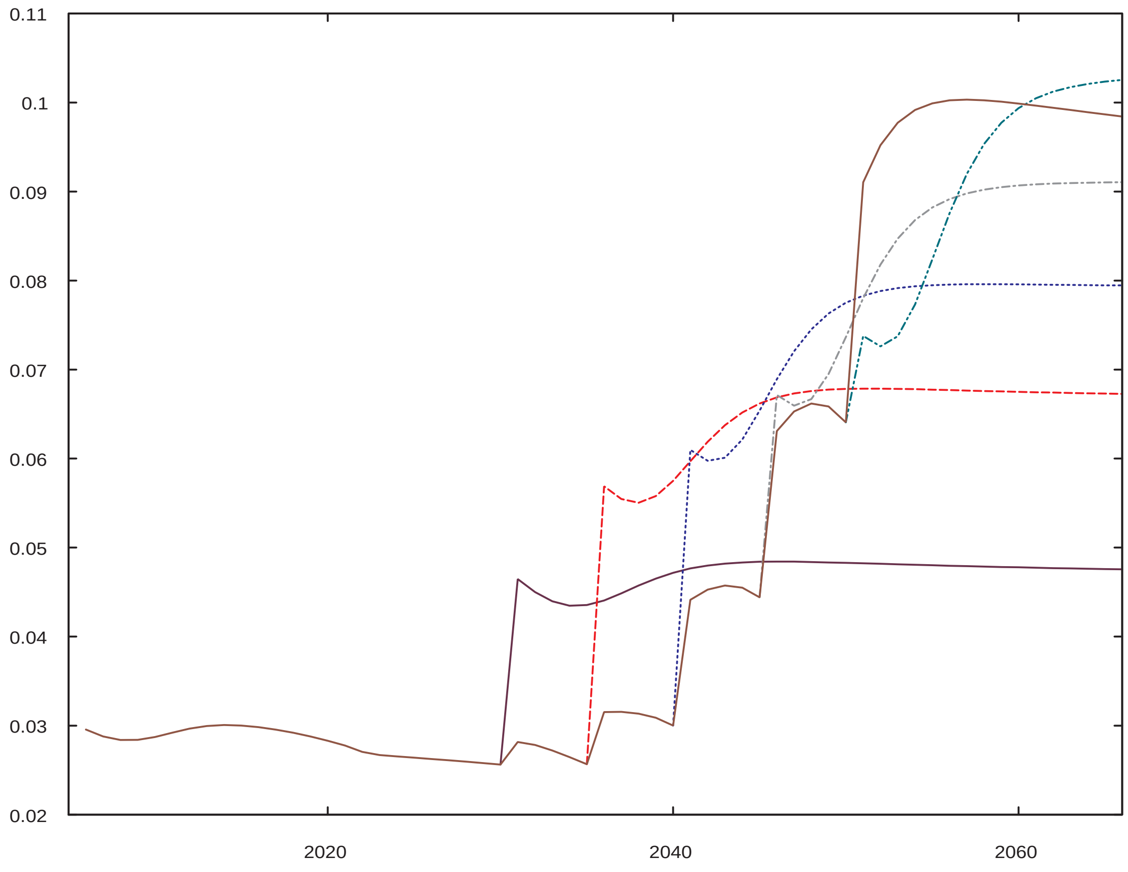
ADV R&D Expenditure



Future Value Carbon Tax



Present Value Carbon Tax

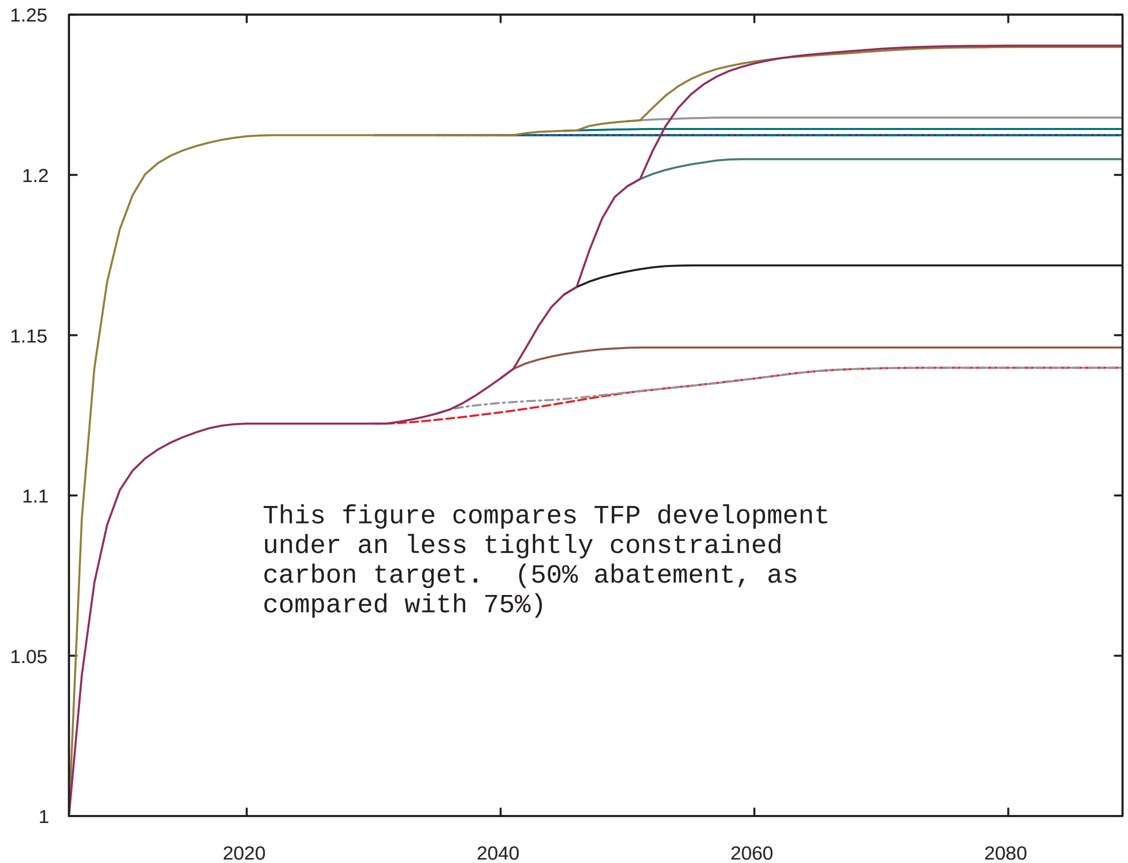


Sensitivity Analyses

1. Sensitivity analysis wrt carbon abatement target (75% versus 50%)
   - CHL productivity development
   - DEF output
   - CHL output
2. Coefficient of relative risk aversion (4 versus 1)
   - CHL output
3. Probability of ADV (0.5 versus 0.8)
   - Carbon tax rate
4. Geometric growth model
   - CHL output
5. Stochastic structure (2020-2040 versus 2030-2050)
   - CHL output

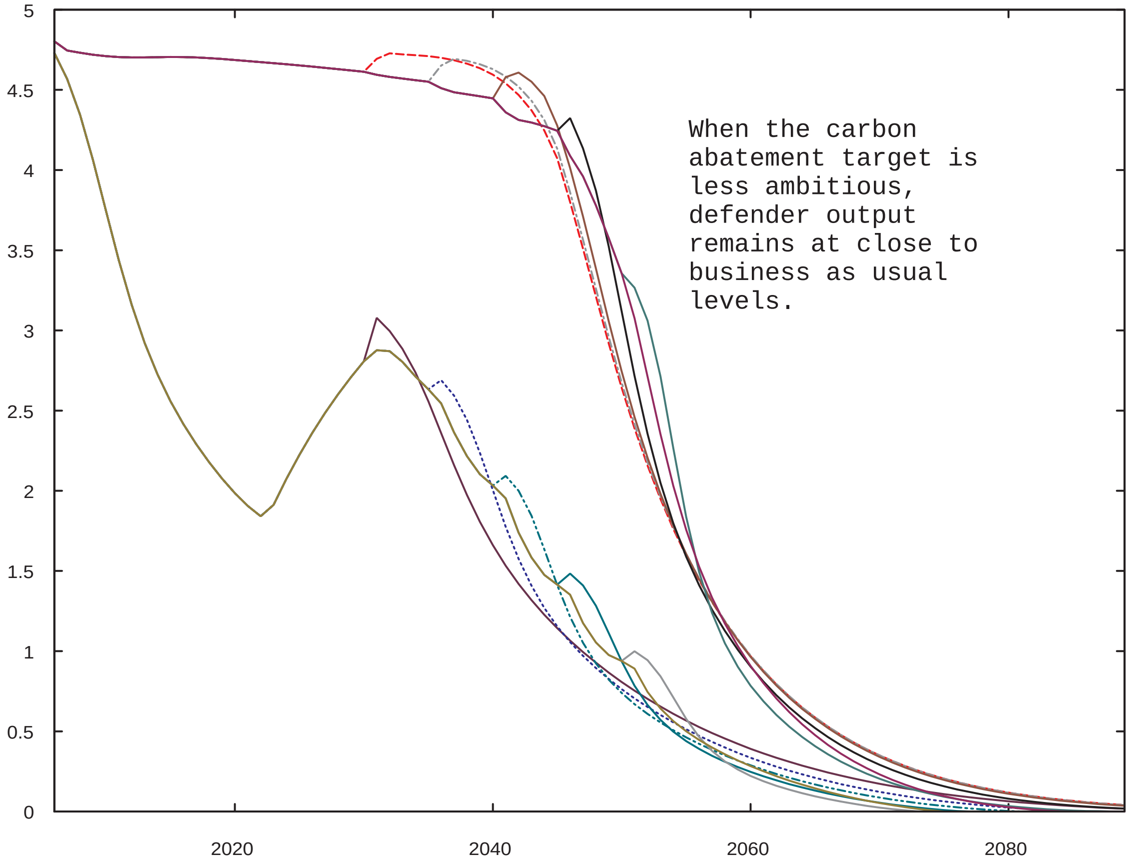
Factor Producticity in CHL

Sensitivity analysis with respect to abatement target.



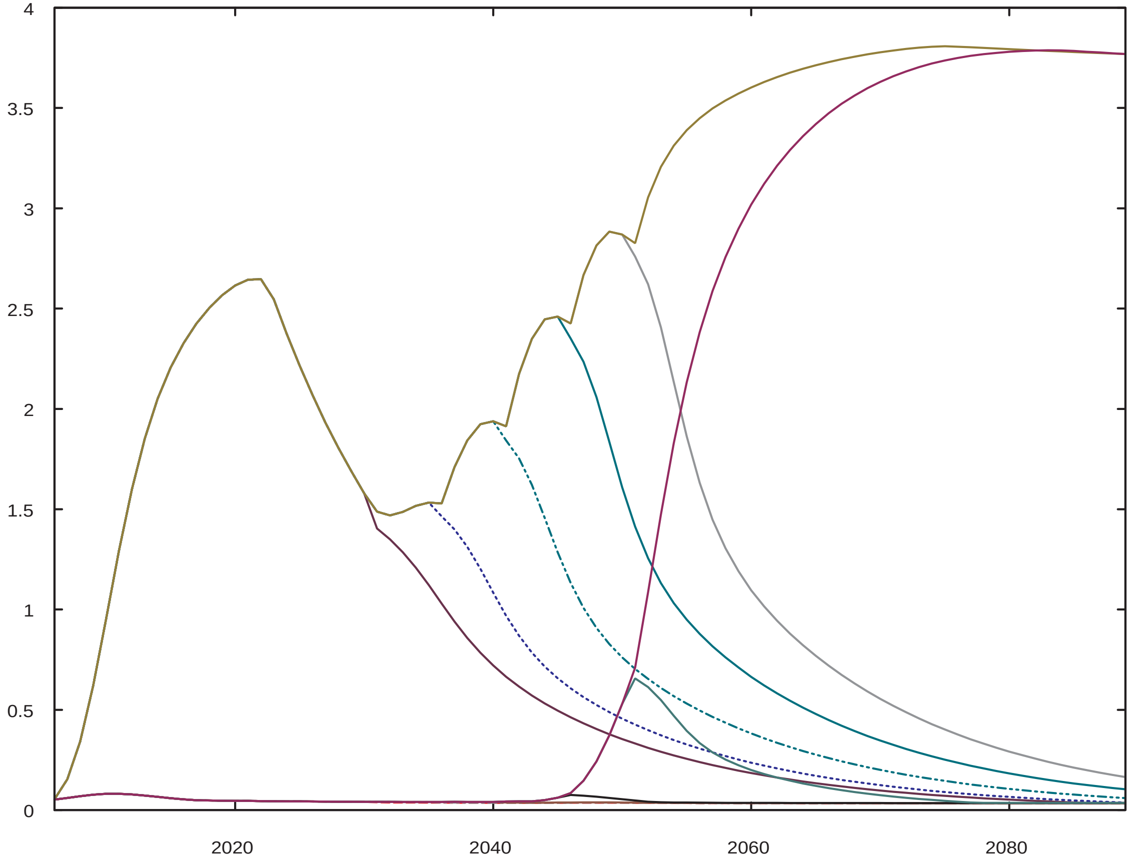
Defender Output

Sensitivity analysis with respect to abatement target.



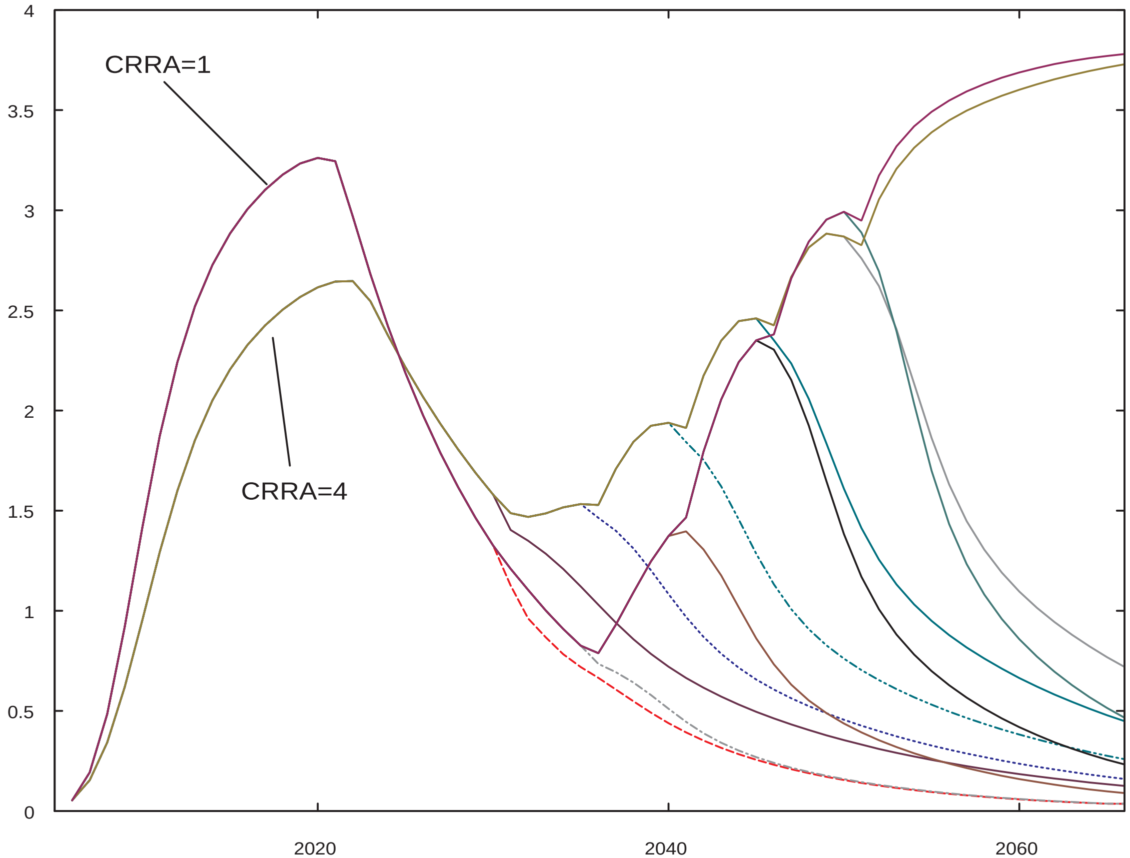
CHL Output

Sensitivity analysis with respect to abatement target.



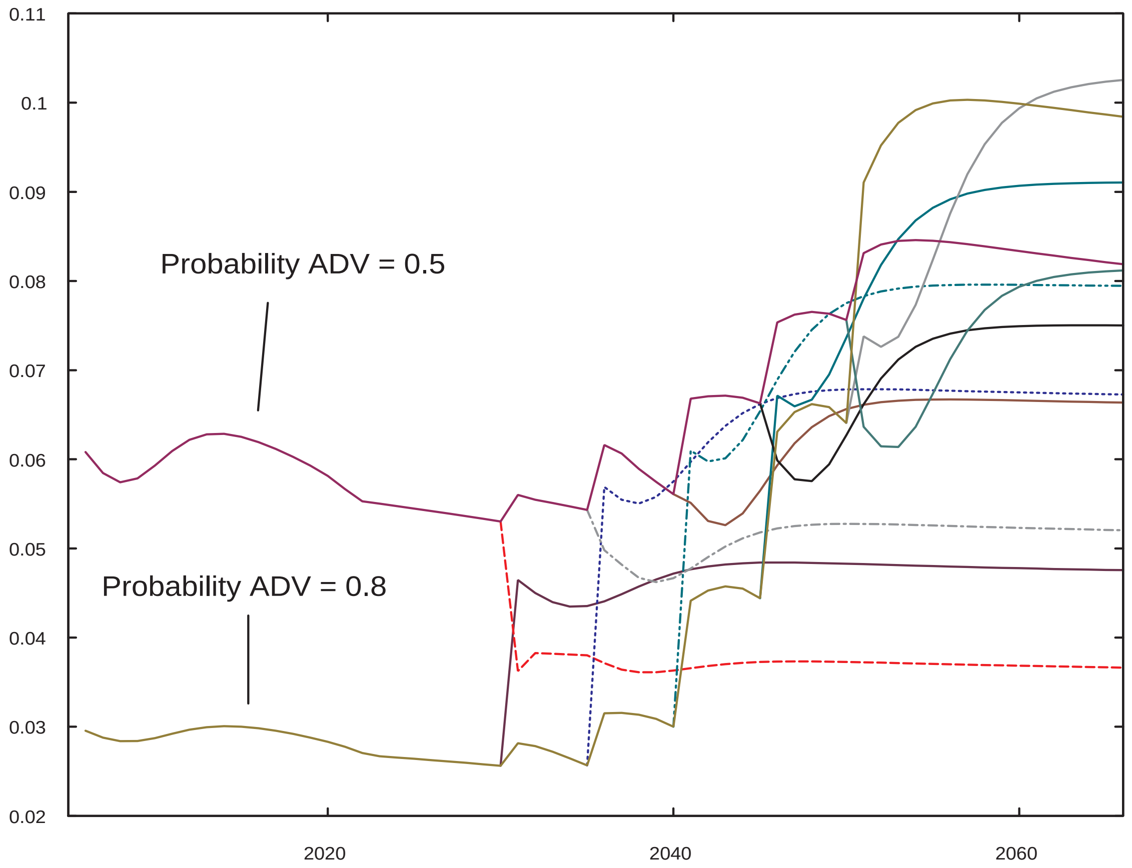
CHL Output

Sensitivity analysis with respect to the coefficient of relative risk aversion.



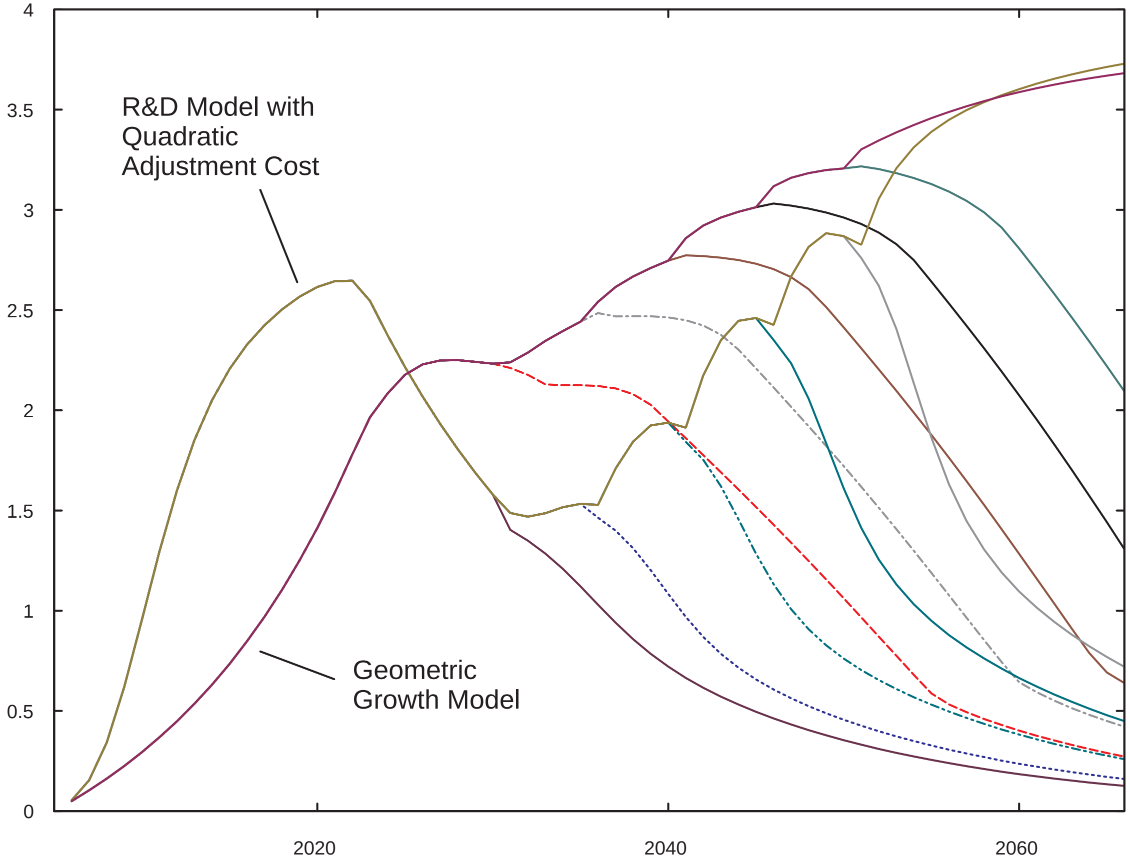
Present-Value Carbon Tax Rate

Sensitivity analysis with respect to the subjective probability of innovation in ADV technology.



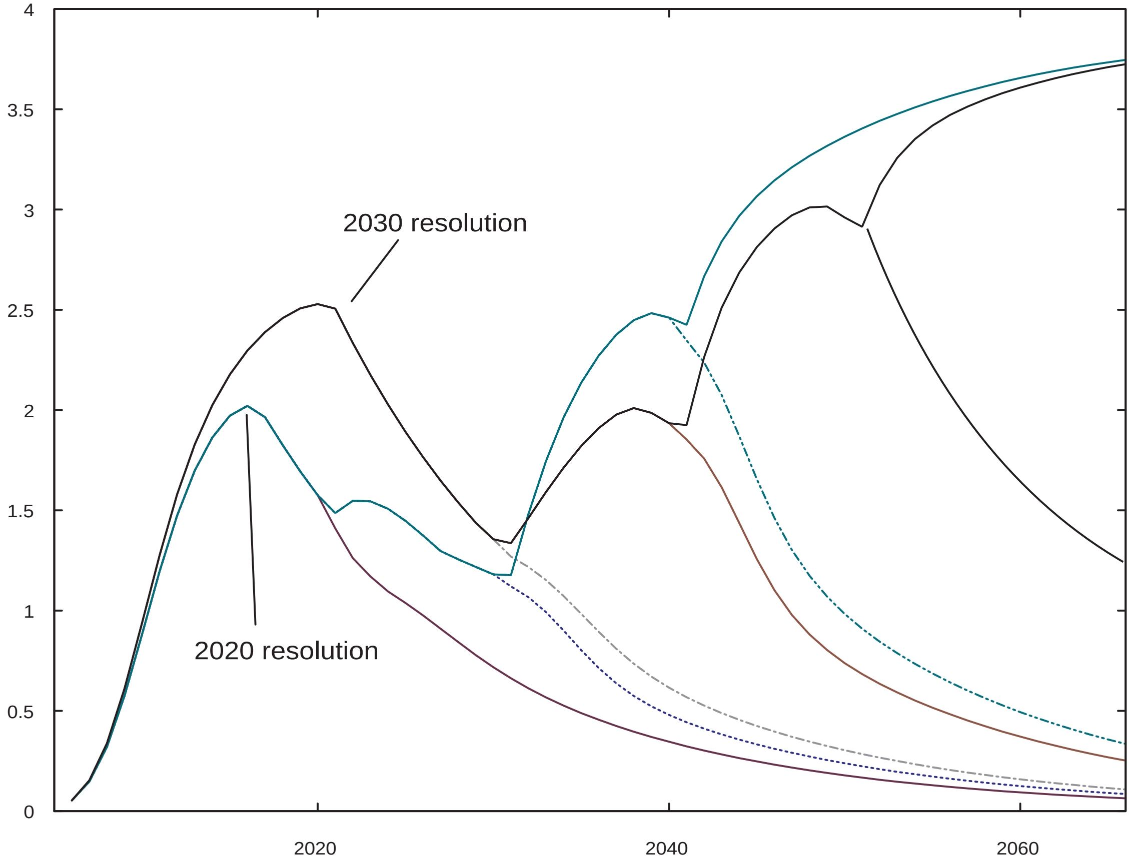
CHL Output

Comparison of R&D model with a geometric growth model.



CHL Output

Sensitivity analysis with respect to the resolution of uncertainty.



Summary of Contribution

1. Consistent model which examines the timing of climate policy instruments.

2. Stochastic programming in a complementarity format provides a convenient means of portraying uncertainty in the future development of energy technology.

3. Clean structural model provides a starting point for evaluating second best policy measures and market failures related to the incentives for private sector innovation.

Future Work (for this and subsequent papers)

1. Estimation of R&D impacts on technical change.

2. Estimation of adjustment costs for individual energy technologies.

3. Representation of incentives for private R&D.

4. Calibration to an integrated assessment model with climate dynamics and long-term stabilization targets.

5. Representation of individual technology options for transportation and electricity sectors.