OPTIMIZING THE PENETRATION OF ADVANCED LOW-CARBON ENERGY TECHNOLOGIES

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Overview

This paper deals with the design of superior pathways transitioning to secure, low-carbon energy technologies for climate stabilization and for adequate, affordable energy. We can conceive of costly energy transitions for which we are not fully prepared. Or we can seek least-cost strategies using dynamic optimization methods.

We know of numerous technological candidates for the medium-term energy portfolio picture:

- Coal-to-liquids,
- Biomass-to-liquids,
- Carbon sequestration,
- Wind and solar energy,
- Nuclear power,
- Efficiency in buildings, vehicles, and equipment, and
- Electricity storage technologies and peak shifting.

Advanced implementations of all these technologies could achieve improved performance, efficiency, costs, and environmental impacts derived from applied research, specific improvements, manufacturing experience (learning-by-doing), computer-aided systems integration, and, in the longer term, from basic research in nanotechnologies, material science, and others. Hence, there are substantial benefits to be captured from optimizing development and adoption rates for the technologies that we will need for an energy transition. This work represents a cooperative effort between the National Energy Technology Laboratory (NETL) and Argonne National Laboratory (ANL).

A present value net benefit function is maximized subject to dynamic constraints including a climate-related constraint. The optimal solution implies that measures need to be taken, beyond what market signals would achieve, to accelerate the steps associated with improving technologies and to help push market adoption and associated technology improvement.

Methods

The method used here is optimal control theory. The dynamic optimization of an energy transition yields first-order necessary conditions of the type that economists expect to be associated with economic efficiency, but with a revision that may be a surprise. Advanced, low-carbon technologies are subsidized so that they are commercialized earlier than under an un-subsidized market. The optimal subsidy is equal to the current value shadow price, summing discounted future costs and benefits.

The current value shadow price satisfies the standard differential equation for a co-state variable. The solution methodology involves a two point boundary value problem, with initial conditions and the phasing out of the subsidy over time.

On the cost side, one of the costs included is the cost of adjustment, which is specified as a function of rapidly accelerating or decelerating energy-related investment spending. Consistent with recent experience, accelerating heavy construction spending bids up prices for skilled labor, materials, and production capacity for specialized components.

Results

Energy economists always incorporate the time-value of money when analyzing energy investments and energy R&D. From a political perspective evaluating environmental impacts, there appears to be a time preference for earlier greenhouse gas emission reductions. Early reductions may be more effective in mitigating environmental damages. This implies that the shadow price on GHG emissions rises at a rate equal to the interest rate minus the rate of time preference associated with trading off early vs. later GHG emission reductions. We examine the sensitivity of the new technology penetration paths and capacity build-up to the parameter representing this difference in discount rates.

We have developed the AMIGA/MARS model that represents and characterizes these technologies for power generation and transportation fuels and their interaction with the economy. The shadow price path on carbon emissions and the shadow price differential equation for measuring the current value of future net benefits of technology improvement and adoption are added to the AMIGA/MARS model equation specification. This allows simulations of the energy market and the economy to be undertaken with optimal technology subsidies, and resulting enhanced technology penetration which reflects future net benefits. These benefits include learning, adoption of specific improvements, and reductions in adjustment costs.

One finding is that the portfolio of advanced technologies taken together can provide gains by integrating energy systems for electricity and transportation fuels.

Conclusions

We find that well-designed transitions have desirable properties: lower carbon charges, longer transitions that begin sooner, greater cost reductions including adjustment cost reductions, and less economic penalty.

There are a number of ways in which development and adoption of advanced technologies can be achieved. The analysis here, however, is more conceptual. Economists have thought that correcting externalities involved raising prices, i.e., higher Pigouvian prices, but never subsidies [Baumol & Oates, 1988]. The results presented here show that technology subsides can arise in optimally correcting dynamic externalities, namely, climate stabilization.

References

W.J. Baumol and W.E. Oates, The Theory of Environmental Policy, Second Edition, Cambridge University Press, 1988.

*This work represents the views of the authors and does not intend to express the views of the National Energy Technology Laboratory (NETL) or Argonne National Laboratory (ANL).