ROLES OF DIFFUSION PATTERNS AND ENVIRONMENTAL BENEFITS IN DETERMINING RENEWABLE SUBSIDIES

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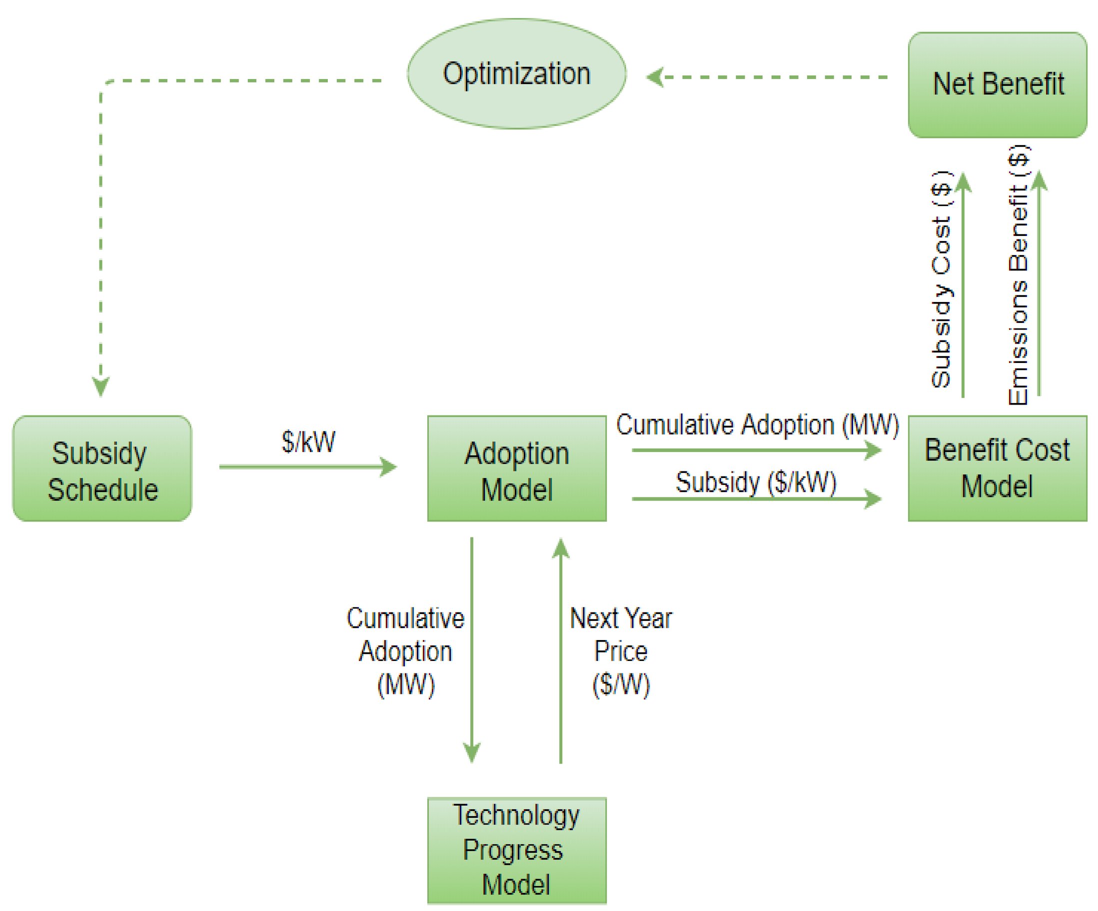
INTRODUCTION

- Clean energy technologies are essential to address environmental emissions, but policies promoting these technologies requires a substantial public spending.
- Two primary economic justifications for subsidy of clean energy technologies are direct environmental benefits in the form of reduced emissions, and indirect technological progress benefit.
- Technology adoption is central to understanding both the direct environmental benefits and the indirect technological progress resulting from a subsidy.
- In this study we show how adoption models can affect both the quantitative and qualitative outcomes of the long-term subsidy support design of clean energy technologies.

FULL TECHNO-ECONOMIC MODEL

- The model integrates three modules: adoption, technology progress, and benefit-cost analysis.
- The **adoption model** uses one explanatory variable, i.e. the NPV. The model is empirically tested using data from different regions and constitutes two regression parameters.
- The **technological progress model** applies a one factor experience curve.
- From the government's perspective, the **benefit-cost model** estimates the net benefit as the emission reduction benefits minus the government's expenditure on subsidies.

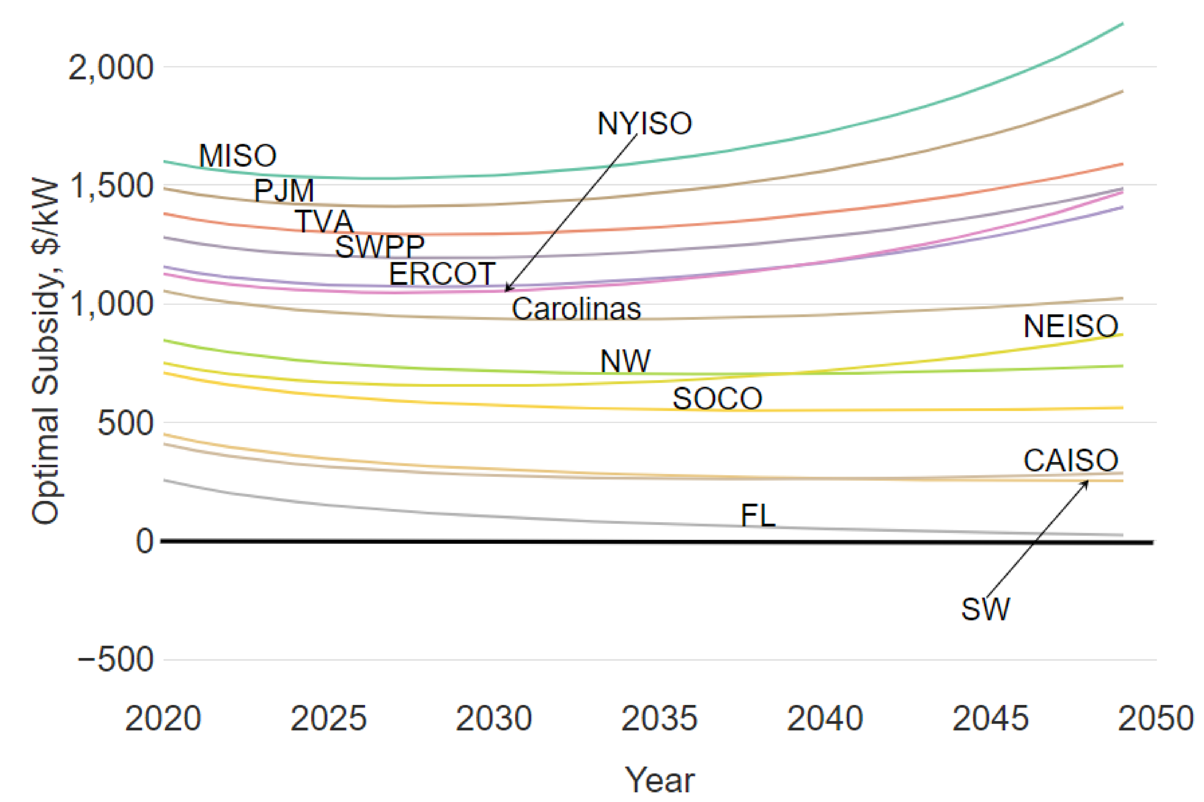


- Technologies: utility-scale wind and residential solar PV
- Geographical scope: 13 ISO regions

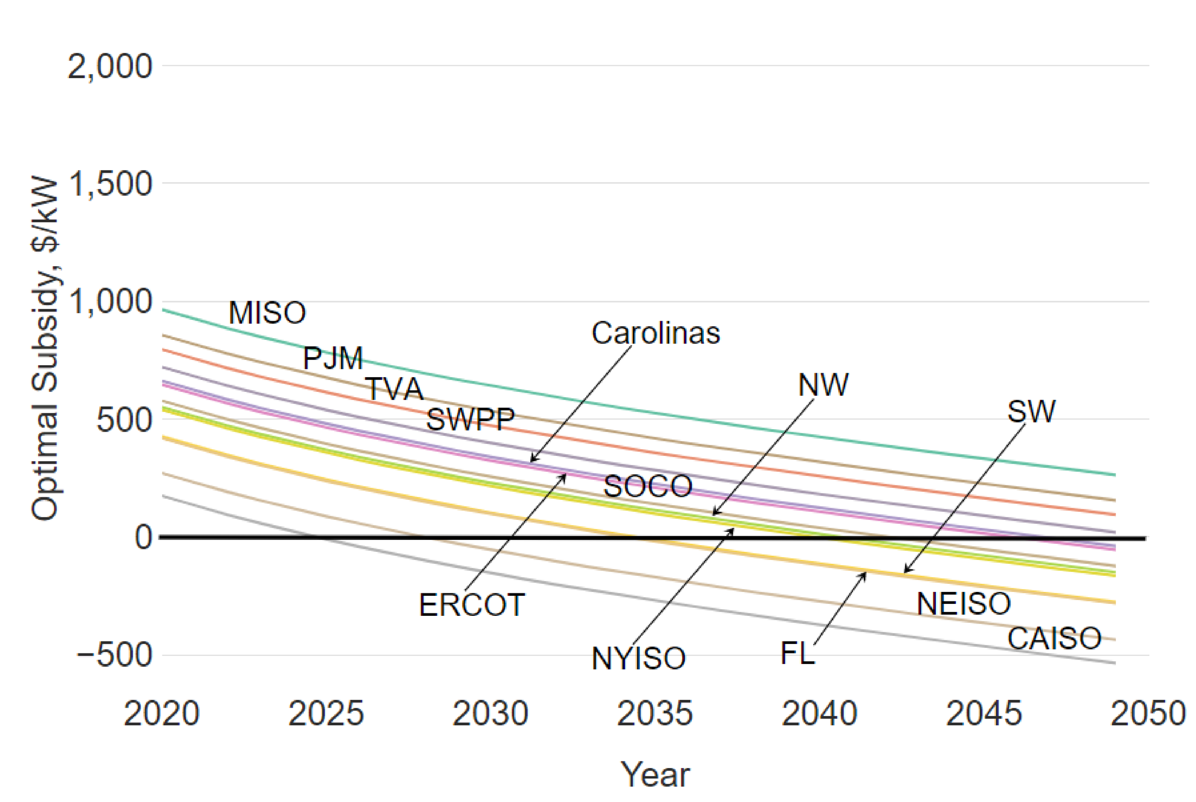
FULL TECHNO-ECONOMIC MODEL: RESULTS

Optimal subsidy schedule that varies across the 13 ISO regions maximizing the national net benefit.

Utility-scale wind optimal subsidy schedule



Residential solar PV optimal subsidy schedule



- The optimal subsidy for utility-scale wind relatively stays approximately the same over time whereas the incentive for residential solar declines to or past zero.

BENEFIT-COST ANALYSIS

$$Net\ Benefit, NB\ (\$) = Stimulated\ Adoption\ (MW) * Benefit, B\left(\frac{\$}{MW}\right) - Adoption\ with\ subsidy, A(S)(MW) * Subsidy\ Cost, S\left(\frac{\$}{MW}\right)$$

- The objective is to determine subsidy level that maximizes the net benefit from policymaker's perspective:

$$\frac{\partial NB}{\partial S} = (B - S) * \frac{\partial A(S)}{\partial S} - A(S)$$

- The *Benefit*, $B\left(\frac{\$}{MW}\right)$ is the discounted environmental benefit of adopting a clean energy technology over a lifetime of 20 years.

RESTRICTED MODEL

- A simpler approach that captures the important feature of the sophisticated model but simple enough for the optimal solution to be solved algebraically.
- The model assumes that the functional relationship between a given subsidy level and the resulting adoption is explained using a simple exponential curve model:

$$A(S) = A(0)e^{a_1 S}$$

where, a_1 is the elasticity of diffusion in $\frac{MW}{\$}$.

- Solving for the optimal solution gives:

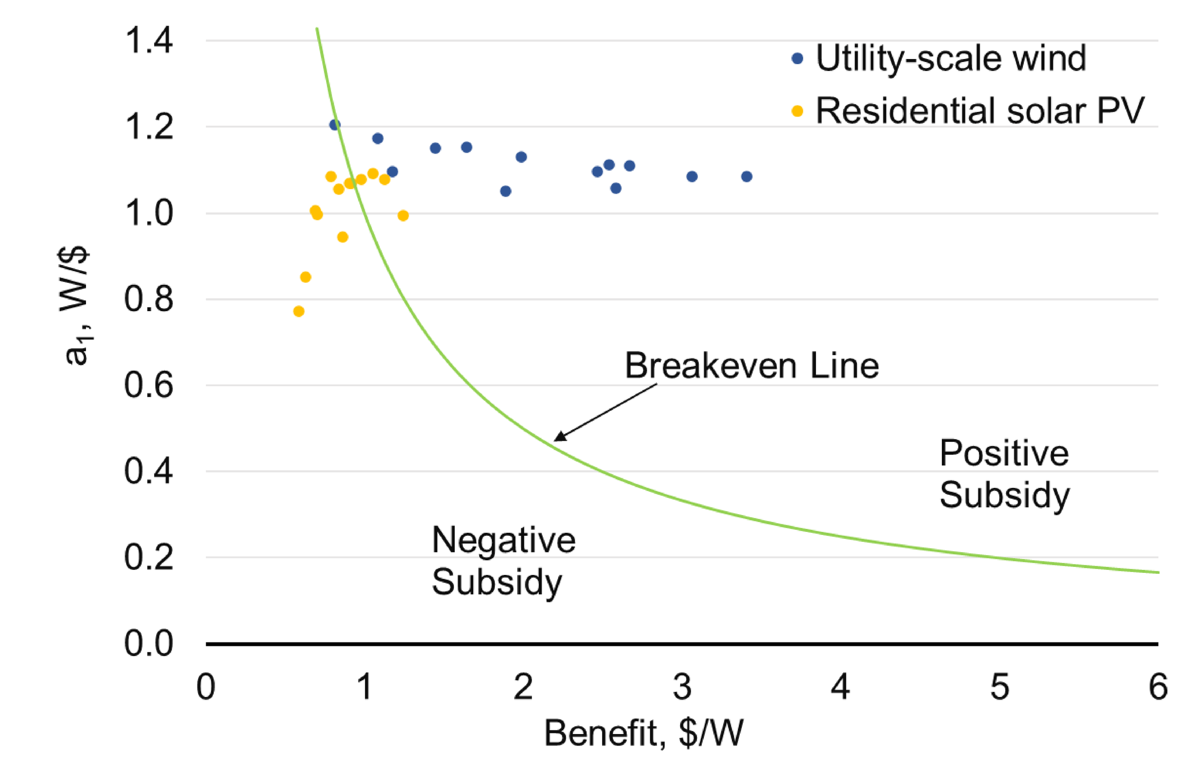
$$S^* = B - \frac{1}{a_1}$$

FULL VS. RESTRICTED MODEL

	Full techno-economic model	Restricted model
Adoption model	$A(S) = \bar{\alpha}\left(1 + \text{erf}\left(\frac{NPV_o + S - \mu}{\sigma}\right)\right)$	$A(S) = A(0)e^{a_1 S}$
Optimal subsidy	Numerically solved (non-linear optimization)	$S^* = B - \frac{1}{a_1}$
Learning rate	15% (residential solar) and 9.8% (utility wind)	0

RESTRICTED MODEL: RESULTS

- Optimal subsidy levels, $S^* = B - 1/a_1$ for utility-scale wind and residential solar PV in 13 ISO regions, where B is the environmental benefit a_1 is elasticity of diffusion.



- The optimal subsidy is positive for wind in almost all the ISO regions, except FL. Meanwhile, optimal subsidy for rooftop solar lies below the break-even line for 9 ISO regions out of the 13.

CONCLUSIONS

- Wind subsides are justified due to a combination of both higher environmental benefits and higher elasticity of diffusion as a function of subsidy level.
- Diffusion of a technology plays an important role in the degree to which subsidies are justifiable.

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