# Supply Strategy for Low-carbon End-use Technology and its Optimal Diffusion Path

*Research in progress*

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Recently, renter or 3rd party-owned contract business models play a key role in diffusion of low-carbon end-use technologies. Based on the research framework from durable good and technology diffusion literatures, we propose an optimal diffusion path by solving social cost minimizing problem. By comparing the results with those under conventional criteria, policy implications will be derived.

## Overview

- Renter or 3rd party-owned business models are playing a key role in the markets for low-carbon end-use technologies such as electric vehicles [1] and roof-top solar PV [2].
- The renter model gives higher affordability to consumers with large capital costs or tight monthly budget constraints [3].
- The renter model is a profit-maximizing strategy, especially for durable good monopolists [4] (i.e, avoding the Coase's conjecture)
- Fiscal incentives and regulatory measures may accelerate the adoption and appropriation of social benefits from demand-side management (DSM)
- Technology diffusion and its rate of adoption depend on the level of perceived utilities net of costs, information effect and other customer/technology specific factors [5].
- In that sense, recent studies propose cost-minimizing [6] or diffusion-maximizing [7] subsidy strategy for residential solar PV using the trade-off between the cost of public expenditures and the rate of diffusion.
- However, in view of climate change mitigation, such as implementing national policy scheme for global 2DS scenario, social cost-minimization is also an important criteria, under which high rate of diffusion does not necessarily lead to the optimum.
- A higher-than-optimal rate of diffusion may require the earlier retirement of incumbent technologies [8], incurring significant social costs (the technology lock-in [9]).
- In addition, we suspect rises in the market price of electricity and in the cost of grid management as more electricity from renewable energy such as solar PV and wind in the end-use sector flows into the grid.
- This implies that although the renter model contributes to accelerating the low-carbon end-use technologies, it may incur higher social costs in fulfilling the carbon budget (which is often modelled as constraints in energy economics literature [10]) in comparison with the seller model.
- In this study, we develop both the rental and sales business models of an installer of low-carbon end-use technology.
- We derive the technology's optimal diffusion path along which the social cost of achieving an emissions reduction target is minimized.

## Methods

- The stylized 2-stage model ($\mathrm{t} = 1, 2$) following [1], [3] and [4].
- Given utility function $\mathrm{U}(\mathrm{X_t}, \mathrm{Y_t}; \theta)$ s.t $\mathrm{p_t^X X_t} + \mathrm{p_t^Y Y_t} \leq \mathrm{I_t}$, where
  $\mathrm{X_t}$ : a service from low-carbon technology at stage t with price $\mathrm{p_t^X}$
  $\mathrm{Y_t}$ : an aggregate service from incumbent technologies with price $\mathrm{p_t^Y}$
  $\theta$ : consumer's time-invariant preference for owning the technology the '*ownership preference*'.
- $\mathrm{I_2}$ : varied along the technology demand $X_1$ with efficiency level $\upsilon_1$ and subsidy level $\lambda$ at stage 1 (e.g. the rise in retail price of electricity).
- With the demand function $X_t(p_t^X; p_t^Y, I_t, \theta)$, the firm decides optimal supply strategy between seller (S) or renter (R) model to maximize:

$$\Pi_i^*\left(X_1^{*\,i}, X_2^{*\,i}; \theta\right) = \max\left\{\pi_{i,S}^*\left(X_1^{*\,i,S}, X_2^{*\,i,S}; \theta\right), \pi_{i,R}^*\left(X_1^{*\,i,R}, X_2^{*\,i,R}; \theta\right)\right\}$$

  when the market is competitive ($\mathrm{i} = \mathrm{C}$) or monopolistic ($\mathrm{i} = \mathrm{M}$)

- Social welfare functions $SW^{i,S}$ and $SW^{i,R}$ are also derived.
- Under fiscal incentive $(\lambda, (1-\delta)\lambda)$, social welfare at optimal $(X_1^{*\,i}, X_2^{*\,i})$ can be written as a function of $(\lambda, \delta)$.
- We can determine the optimal set $(\lambda^*, \delta^*)$ with little algebra that maximizes either the social welfare or the total diffusion, $X_1^{*\,i} + X_2^{*\,i}$, under the constraint of total subsidy expenditures.
- These results are compared to the results from the cost minimization problem with a set of constraints, which is given as follows:

$$\min_{\lambda,\delta} Social\ Cost\left(r_1, r_2, \bar{c} - c, X_1^{*i}(\lambda), X_2^{*i}\left(\lambda(1-\delta)\right), \upsilon_1, \upsilon_2, \lambda, \delta\right)$$

- Here, c is the total amount of carbon emissions $e_1(I_1 - X_1^{*i}(\lambda)) + e_2(I_2 - X_2^{*i}(\lambda(1-\delta)) = c$ from incumbent technologies.
- If the c exceeds (is lower than) the carbon budget $\bar{c}$, then permits are purchased (sold) with price $r_t$

## Results

- Consumers under the seller model would pay upfront costs more or less than twice the rental price.
- Consumers are divided into two groups by the level of ownership preference $\theta$; the firm chooses its profit maximizing supply strategy accordingly (framework proposed by [1], [3]).
- More adoption is expected in stage 1 compared to the seller model.
- Conflicting forces at stage 2: $X_2$ would cut more deeply due to an increase in $X_1$ and an associated decrease in $I_2$, whereas more adoption at stage 1 gives learning and information effect.
- In addition, relative to the monopoly case, social costs in the perfectly competitive market are expected to decrease but not drastically, due to an increase in subsidy expenditures.
- The ultimate goal is to extend the model to accommodate the carbon budget constraint, providing policy-relevant insights into the optimal diffusion path under the renter as well as the seller model.
- Subsidizing renter or 3rd party-owned contract models may not turn out to be cost-effective compared to the seller model.

## References

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