# *Policy, investment, and improvements in wind power in California*

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## Overview

Policy makers must choose from a diverse set of policy instruments when trying to stimulate innovation in low-carbon energy technologies. Drawing on earlier debates in the economics of innovation, energy technology policy studies frequently distinguish between ``demand pull," government actions that enlarge the market for a new technology, and ``technology push," those that influence the supply of new knowledge. While many have criticized the reduction of the complex process of innovation to two causal factors, the notion per se that policy can induce investment---and consequent improvements---in technologies by creating markets for them enjoys support from a wide range of disciplinary perspectives. This paper uses the case of wind power in California from 1975 to 2001 to evaluate this hypothesis. Both the California state and U.S. federal governments implemented several demand-side policies relevant to wind power. By increasing the profitability of wind power, these incentives stimulated rapid investment in and diffusion of the technology. They also provided opportunities for important incremental improvements in the technology through learning-by-using. Demand created by these policies was less effective in stimulating inventive activity, as measured with patents; patenting activity declined as investment in new wind power development increased during the mid-1980s. Analysis of the most frequently cited patents shows that their decline during that period is almost entirely attributable to a precipitous drop in patents that provided alternatives to the increasingly dominant 3-blade, upwind, horizontal-axis design. Explanations for this apparent lack of responsiveness to demand-pull focus on policy uncertainty, lags in investment payoffs, and the convergence on a dominant design.

## Methods

The application of the demand-pull hypothesis to technology policy encompasses a series of arguments: that policy can enhance demand for a technology, that increasing expected future demand raises the payoff to successful innovation, and that higher payoffs stimulate efforts to improve the technology. Using the case of California wind power, this study assesses three hypotheses related to the effect of *demand pull* policies on distinct aspects of the innovation process:

- H1: Demand-side policies increased the profitability of wind power and stimulated *diffusion* of the technology.
- H2: Policy-led diffusion created opportunities for *learning-by-using*.
- H3: Policy-led demand created expectations of larger future markets, raising incentives for investments in patentable *inventions*.

A series of analyses are assembled to evaluate these hypotheses. First, the history of policies relevant to wind power is documented and their effect on the profitability of wind power as an investment is calculated. This study uses profitability, the difference between the cost of wind power and the price at which utilities purchase power, as a proxy for expected future demand. Second, *diffusion* of the technology is measured in both megawatts of installed capacity and investment in constant dollars.

Third, evidence of *learning-by-using* is obtained using a time series of *capacity factors* for California wind turbines. Previous work distinguished between learning-by-*doing*, in which a producer improves a good through knowledge gained through accumulated experience in manufacturing, and learning-by-*using* in which consumers of a good increase its productivity by making changes to the way they operate it, based on insights gleaned from their experience in using it. In this case, the good of interest is a wind turbine, and the relevant experience is that which operators acquire in *using* wind turbines, so the analysis focuses on learning-by-using rather than learning-by-doing. Capacity factor captures improvements in the choice of turbine siting, wind farm configuration, and operation and maintenance activities, which are difficult to replicate in laboratory or even demonstration settings.

Fourth, three measures of patenting activity are used to assess the intensity and characteristics of inventive activity Patents provide an attractive way to measure inventive activity for several reasons: comprehensive data is publicly available, the technical characteristics are described in detail, the definition of what constitutes a patent in the U.S. has changed little for over 200 years, and every patent is categorized by experts using a standard classification scheme. Patent citation frequency is used here to address issues about heterogeneity in the quality of patented inventions.

### *Results*

The data assembled for this case generally support the demand-pull hypothesis with respect to diffusion (H1) and learning-by-using (H2). However, they provide little evidence that demand-pull polices stimulated inventive activity (H3).

## Conclusions

In a sense it is neither a surprise nor a disappointment that patenting declined just as California wind power became a multi-billion dollar industry. The cost of California wind power declined by a factor of ten without any radical changes to the 3-blade, upwind, horizontal-axis design. By the 2000s, the accumulation of incremental changes to blade shapes, transmissions, power controllers, and the gradual scaling up of the sizes of turbines brought wind power close to being competitive with power from natural gas, even without subsidies.

But it is far from clear that this path was optimal. It took three decades between the time that studies correctly predicted that turbines would have to exceed 1 MW to be competitive with conventional electricity sources and when that scale was reached. Wind power provides less than 1% of electricity production in the U.S. and as the windiest feasible sites are used up, substantial cost reductions are still needed. It is impossible to assess whether a technology strategy that enabled “coupling” of technical opportunity with market opportunity, a la Freeman (1974), by combining an R&D program with a demand-side program would have accelerated diffusion. Nor is it possible to assess whether increasing the longevity of demand-side measures would have improved outcomes. However, it is clear that the distinct switch from a technology-push policy regime in the 1970s to a demand-pull one in the 1980s provided stronger incentives for investment in incremental improvements to the dominant design than for investment in alternative designs, or even improvements to the dominant design that were novel enough to be patentable. These results urge further study—and perhaps also caution among policy makers—about the extent to which public technology strategies that rely heavily on demand-pull provide sufficient incentives for innovation when non-incremental innovation may be needed to achieve societal goals.

## References

Chris Freeman. *The economics of industrial innovation*. The MIT Press, Cambridge, MA, 1974.