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Stimulating Learning Investments for Renewable Energy Technology

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Abstract

Learning investments for a technology is the difference between actual price and price at break-even, i.e. the additional cost for the technology compared to the cost of having the same service from technologies which the market presently considers cost-efficient. The experience curve phenomenon shows that deployment will reduce unit price and learning investment per unit will decrease and become zero when the break-even point is reached. The learning investments thus indicate the cost, which will have to be supplied through the market in order to make the technology competitive. The learning investments are estimated from experience curves for three technologies: solar heated swimming pools, wind energy and residential photovoltaic systems. Comparisons are made with public R&D spending for these technologies. The results indicate two distinct phases in the development of the energy technologies from concept to market maturity: a first phase dominated by public R&D support and a second phase dominated by learning investments on the market. The learning phase may require public deployment policies to provide the technology with learning opportunities on the market. An important question is how governments can stimulate learning investments from private sources. The paper discusses how efficient government deployment programmes for the three technologies have been in this respect.

1. Introduction

Public funding for energy technology R&D shows a decreasing trend during the last decade. The reductions are large compared to the efforts during the 1980's. The trend is a cause of concern in view of the importance to develop a technology response to climate change. However, the experience curve phenomenon indicates that technologies learn and improve by being deployed on the market (Boston Consulting Group, 1968, Abell and Hammond, 1979). This process also activates R&D efforts within private industry (Watanabe 1995, 1999). In fact, the rationale for government deployment programmes is that technologies need market experience to reach commercial maturity (IEA, 2000).

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[∞] International Collaboration on Experience Curves for Energy Technology Policy, see http://www.iea.org/excetp/excetp1

Experience curves express the simple fact that experience is needed in order to improve performance. In a competitive environment one would expect actors to search for technology experience in that environment where learning is most efficient. The trends in R&D may therefore express a natural shift in the learning environment for a developing technology. Creating and testing major new solutions is a high-risk undertaking, and government sponsored research facilities and demonstration plants provide the most efficient form for technology learning. The function of the market during this work is to provide benchmarks against which the performance of the new solutions can be compared. However, when price becomes the issue, the market itself is the most efficient teacher. For most of the technologies researched during the 1980's, price is the most important barrier keeping them out of the market. The logic of the argument then leads us to the conclusion *that for these technologies* it is more important for the governments to provide learning opportunities on the market than to provide R&D funding (Koch, 1999).

The purpose of this paper is to illustrate the shift in the learning environment for energy technologies through three case studies described in detail in IEA(2000) and Wene(1999b). The implication from the studies is that the shift in learning environment requires a shift in the focus for energy technology policy. The policy analyst need to focus stronger on developing methodology for designing and assessing the efficiency of government deployment programmes and international collaboration on such programmes.

The following section introduces a simple input-output model for the experience effect and uses this model to discuss relations between public R&D support and deployment policies. Section 3 defines the concept of learning investments, which is used to estimate the investments in learning that has to be done through the market in order to make the technology commercial. Section 4 discusses the results from three case studies.

2. Influencing the Learning System: Public R&D and Deployment Policies

Learning curves were first quantified and reported in the airplane industry (Wright, 1936). Arrow (1962) draw the economic implications from "learning-by-doing", but the experience effect was firmly established within the Management sciences through the work of the Boston Consulting Group (Boston Consulting Group, 1968, Abell and Hammond, 1979). The original learning curves focused on the costs of individual inputs to the factory process. The Boston Consulting Group (BCG) looked at total cost and widened the inputs to the learning system to include "all of the cost elements which may have a trade-off against each other. This therefore means all costs of every kind required to deliver the product to the ultimate user, including the cost of intangibles which affect perceived value. There is no question that R&D, sales expenses, advertising, overhead, and everything else is included" (p.12). BCG introduced the term experience curves for the curves relating *total* cost and cumulative quantity, and their terminology is used in this paper.

Figure 1 shows the basic model for a learning system based on cybernetic theory (Ashby, 1964) and applied to the experience curve phenomenon (Wene, 1999a, IEA, 2000). The learning system could be a factory production line for aeroplanes in the case of learning curves, or the industry for production and sales of PV modules in the case of experience curves. The model implies that learning is the result of activities producing outputs, which are assessed by a competitive environment. Conversely, a system that has no output will not learn, meaning that a technology which is not produced and deployed cannot start the ride down the experience curve. The performance, P, of the system is the ratio of input over output and we have the experience curve for the learning system

$$P(t) = P_0 * X(t)^{-E} \qquad \text{(Eq. 1)}$$

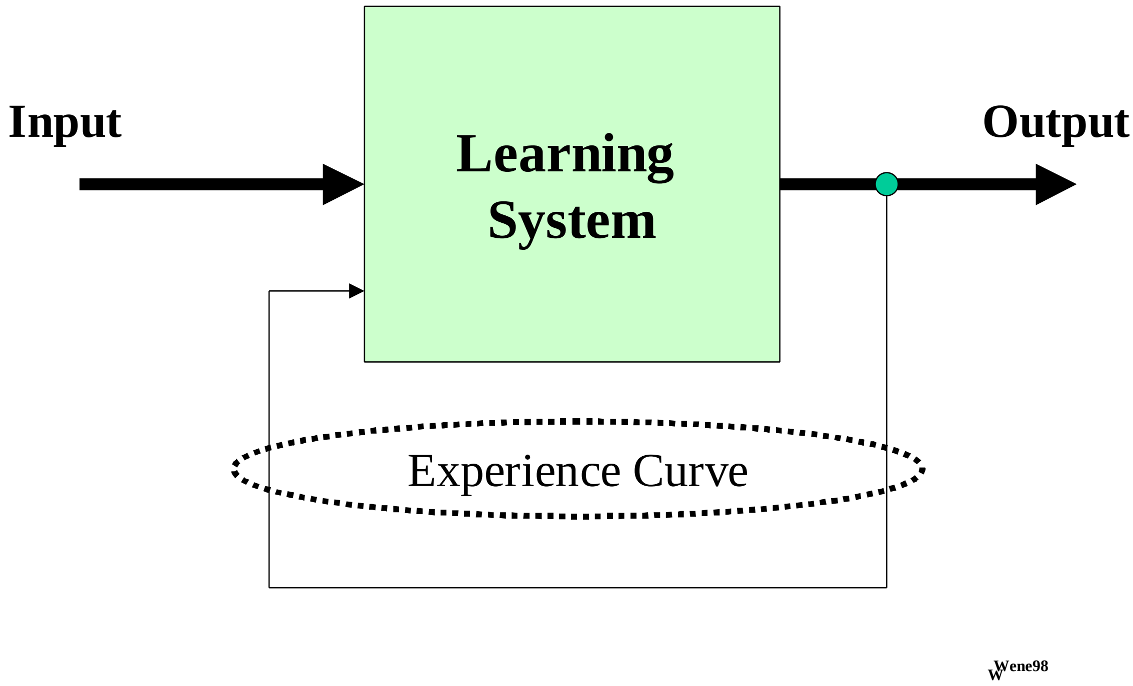

Figure 1. Input-output model for a learning system with the experience curve as a measure of the efficiency of the feedback, or learning loop, for the system (Wene, 1999a, IEA, 2000).

P(t) is the performance at time t, X(t) is the cumulative output from the learning system until time t, P_0 is a constant and E is the experience parameter characterising the learning rate for the system. In the literature, comparisons between different experience curves are made by doubling the cumulative output; the corresponding change in performance is referred to as Progress Ratio, PR

$$PR = 2^{-E} \qquad \text{(Eq. 2)}$$

A progress ratio of 80% means that the price is reduced to 0.8 of its previous level after a doubling of cumulative sales. Sometimes, the term Learning Rate is used

$$LR = 1 – PR \qquad \text{(Eq. 3)}$$

A learning rate of 0.2 means that price is reduced by 20% for each doubling of cumulative output.

The basic learning model does not make any hypothesis about the processes going on inside the learning system; in fact it considers this system as a black box for which only input and output can be observed.[1]

The work by Watanabe (1995, 1999) provides insights into the mechanisms within the black box. Watanabe studies solar cell production in Japan and looks at the interactions between public and industry R&D, production and the technology stock created by PV technology R&D. Figure 2 interprets his results in the basic learning model. The “+” and “-” identify a cycle, which includes the crucial elements of the experience curve. An increase in “Output” or sales increases “Production”, which stimulates “Industry R&D”, which enlarges “Technology Stock”, which boosts “Production” and reduces “Total Cost”, enhancing market opportunities and thus sales. The cycle reinforces itself; it is a “virtuous cycle”. There is a double boost to production coming from the sales on the market and from the improvement in knowledge through R&D.

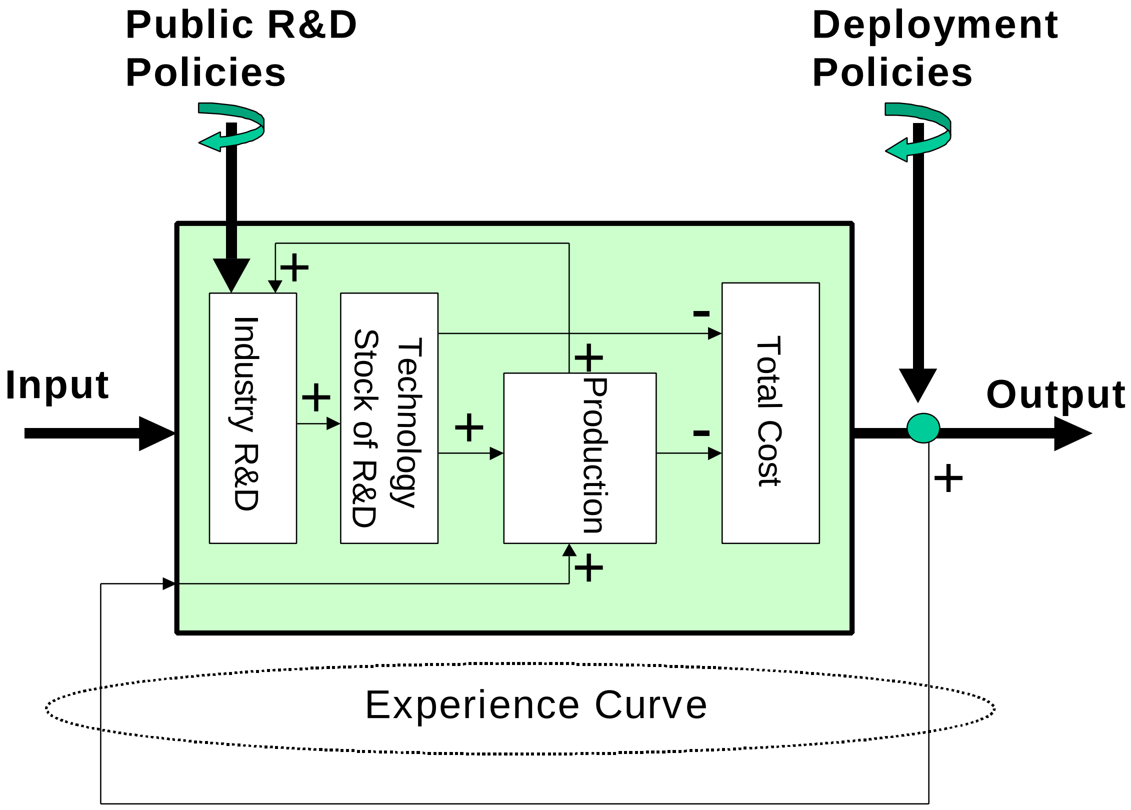

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Figure 2. Influences on the learning system from public policy. Factors influencing the total cost are taken from Watanabe (1995). The experience curve interpretation is from Wene(1999a), IEA(2000).

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[1] The input-output model for learning includes price reductions due to economies of scale. Critics of the experience curve concept have argued that the observed correlation could as well be explained by scale effects (see, e.g., Hall and Howell, 1985). Regarding the discussion on how to separate experience and scale effects, Abell and Hammond (1979, p.114) note that “(t)he confusion arises because growth in experience usually coincides with growth in size of an operation”. They conclude: “Usually the overlap between the two effects is so great that it is difficult (and not too important) to separate them. This is the practice we will adopt from here on (while remaining alert for those exceptions where scale effects can be achieved alone, such as in high fixed-cost, capital-intensive industries.)” We will follow the lead of Abell and Hammond in this paper and not separate the two effects.

Figure 2 shows that public R&D can influence industry R&D, but its inflow has to be mediated by the internal industry R&D process to be able to add to the industrial stock of knowledge. Public R&D does not directly influence total cost. It can seed the learning process within the industry, but without market interaction there is no virtuous cycle and no substantial cost reductions.

The analysis suggests a two-pronged technology policy. Firstly, technology policy requires public R&D to initiate research on uncertain technology options, which present a high investment risk, followed up by pre-competitive public R&D expenditures to seed the industry R&D process and keep it on track. Secondly, technology policy requires deployment measures to insure market introduction of technologies which are not yet competitive.

The hypothesis of a two-pronged energy technology policy needs quantification. In the following section we use experience curves to define learning investments, which characterise the second phase of technology development.

3. Learning Investments

Figure 3 indicates how learning through cumulative production overcomes the cost barrier for photovoltaic modules. For photovoltaic systems to compete on the present huge market for central power stations, the cost of modules has to be brought down to 0.5 USD/W_p, indicated by the "Fossil fuel alternative" in the diagram. A progress ratio of of around 80% is expected (Tsuchiya, 1989, Williams and Terzian 1993, Nitsch 1998). Extrapolating the experience curve shows that bringing modules to break-even with existing electric technology requires a cumulative production of about 200 GW. This indicates a large effort to reach a commercial situation, however, there are niche markets that may act as stepping stones for the descent to break-even with existing conventional technologies (Tsuchiya, 1989).

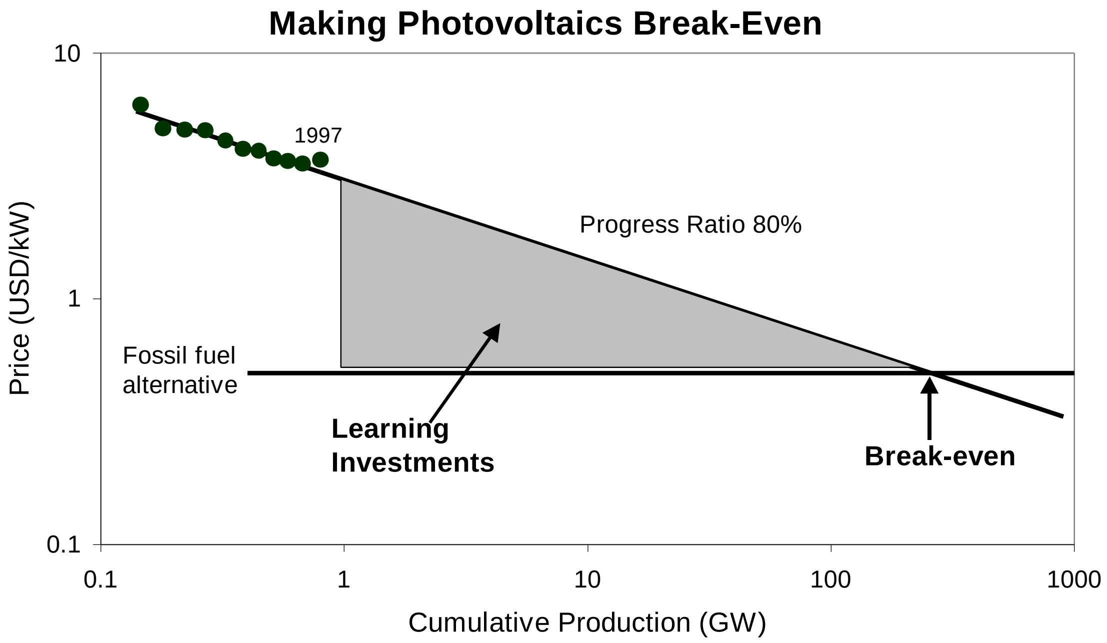

Figure 3. Break-even and learning investments for photovoltaic modules with progress ratio of 80%.

Resources will be needed for the ride down the experience curve; that is for the learning efforts, which brings prices to the break-even point. An indicator for these resources is the difference between actual price and price at break-even, i.e., the additional costs for the technology compared to the cost of having the same service from technologies, which the market presently considers cost-efficient. We will refer to these additional costs as *learning investments* (IEA 2000).[2] The name implies that they are investments in learning to make the technology cost-efficient, after which they will be recovered as the technology continues to improve.

The remaining learning investments for photovoltaic modules are indicated by the shaded triangle in figure 3. The sum of all future learning investments needed to bring module technology to the break-even point indicated in the figure is 60 BUSD. This is a large investment in learning, considering the learning investments of 3-4 BUSD made in PV modules until 1998. The challenge is to put policies in place, which mobilises resources on the market for these investments, e.g., through niche markets. Public demonstration programmes and subsidies can only seed this process.

Learning investments primarily reflects resources for technology learning provided through market mechanisms, and they always involve commercial actors on the market. For smaller programmes, government expenditures for experimental and demonstration installations may be a substantial part of total learning investments. However, for technologies such as photovoltaics, wind power, biomass, or heat pumps, resources provided through the market dominate the learning investments. The learning investments includes government R&D expenditures for the building of experimental or demonstration plants, provided that those expenditures increase the cumulative production. Expenditures not included are, e.g., R&D funds for universities and research institutes, measurement programmes around a demonstration site, etc. The results generated from such funding are common goods, which are free on the market. The learning investments do include, however, cost of research and development activities carried out by the commercial market actors, who ultimately have to recover those costs through market revenues.

Learning investments and public RD&D measure different parts of the resources needed for technology learning. It is therefore not surprising that until today the RD&D spending on photovoltaics by the IEA countries is twice as large as the learning investments. It is also to be expected, that public RD&D spending will dominate the first part of the life cycle of a new technology.

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[2] In the case of an alternative electric technology without fuel cost, the specific learning investment, LI, per kW of new capacity is

$$LI = P(\text{alternative}) - [8760 * \rho * p(\text{market}) - O\&M]/\text{annuity}$$

P(alternative) is the price per kW for the new technology at the time of investment and p(market) is the price per kWh of electricity from the currently cost-efficient (fossil fuel) technology. ρ is the load factor and O&M are the operation and maintenance costs at the break-even point for power plants with the alternative technology. The second term is the break-even price. More detailed calculations of learning investments therefore require databases with time series not only of technology prices and installations, but also of market prices and interest rates. As a first approximation, we assume in this paper that the break-even price stays constant during the whole learning period. Current prices for established fossil technology reflect learning through considerable cumulative output and additional capacity will therefore only slightly reduce prices.

4. Results from Case Studies

Figures 4-6 show results from three case studies, which are presented in detail in IEA (2000) and in Wene (1999b).

The three technologies are in different stages of their life cycle. Solar heated swimming pools are a commercial technology since the beginning of 1990's (Lawitzka 1992, 1999). Wind turbines (Durstewitz and Hoppe-Kilppe, 1999) are close to their break-even point. Photovoltaics is still a long way off from being able to compete with fossil technologies for central power stations. However, if the Japanese programme proceeds as planned residential systems are expected to reach self-propelling niche markets in six to seven years. The analysis assumes that such niche markets are found at 3 USD/Wp, which is in accordance with the conclusions of the Utility Photovoltaic Group (1994).

Wind power in Germany and photovoltaics in Japan show a very clear two-step development process. The first phase is driven by public RD&D expenditures, while technology learning in the second phase is taking place on the market and learning investments dominate over public RD&D expenditures. The work by Watanabe (1995, 1999) suggests that these learning investments contain considerable private industry R&D.

For solar heated swimming pools, the data do not permit the distinction between R&D expenditures and expenditures for experimental and demonstration plants, which in this case provides important contributions to cumulative production. The curve marked "RD&D" in figure 4 therefore contains considerable support for learning investments. This explains why the two phases are less distinct in this case. The learning investments show two peaks due to the technology structural change within the learning system. The first peak represents learning investments into collector systems, from 1982 all learning investments were made in absorber systems.

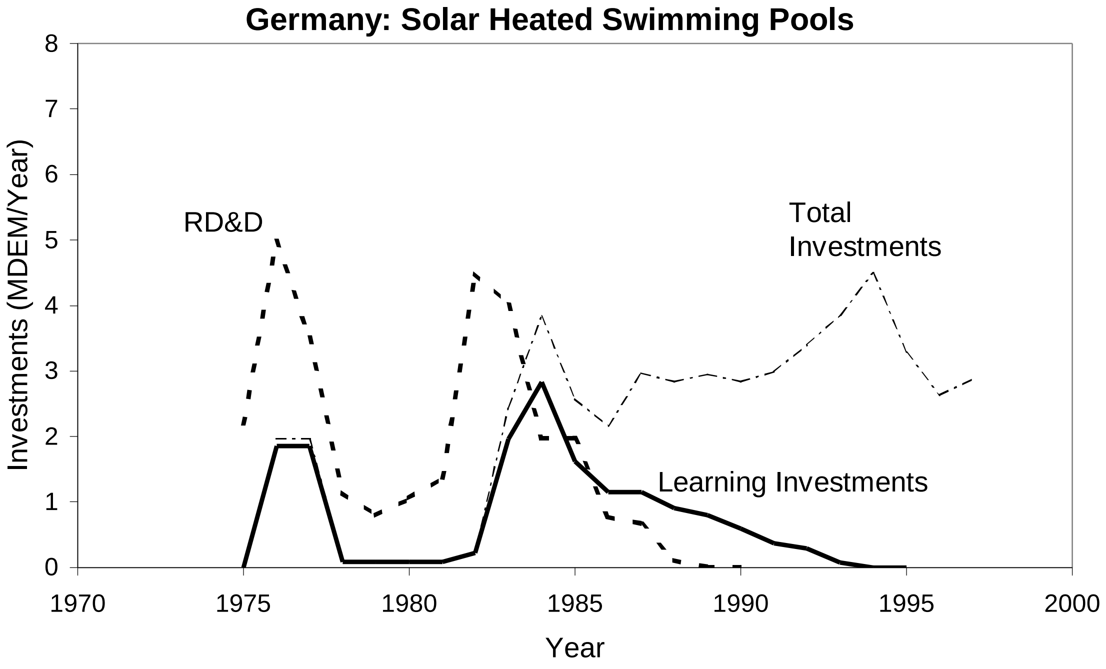


Figure 4. Public RD&D expenditures and Learning Investments for solar heated swimming pools in Germany 1975-1997. The thin broken line shows the total investments in this technology in Germany.

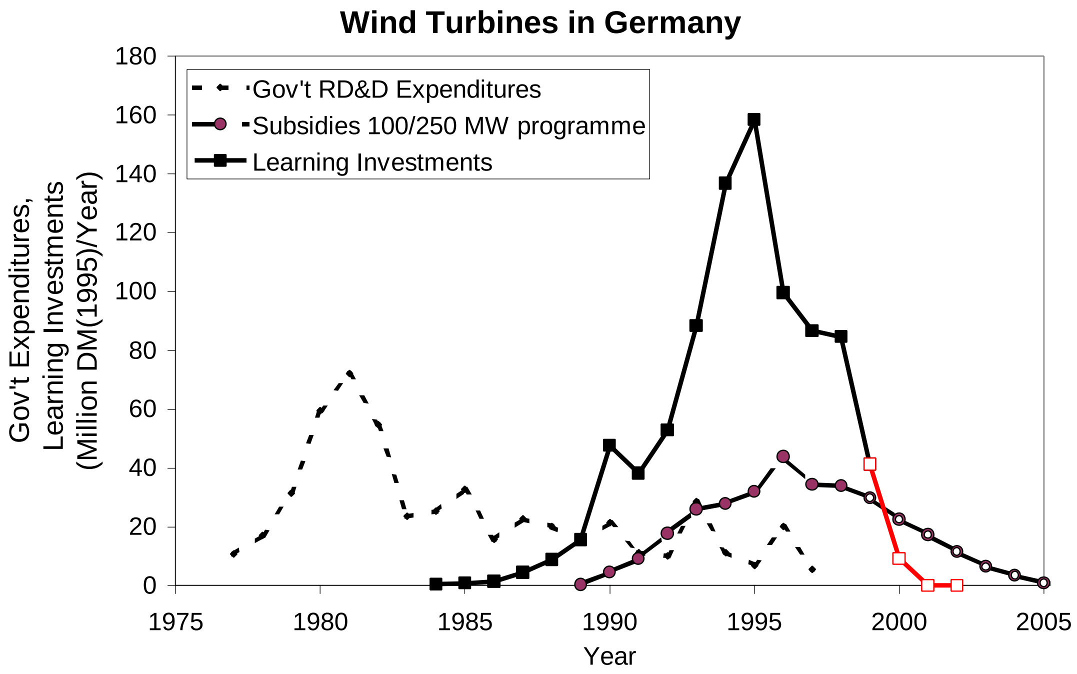


Figure 5. RD&D expenditures and subsidies for wind power, and Learning Investments in wind turbines in Germany.

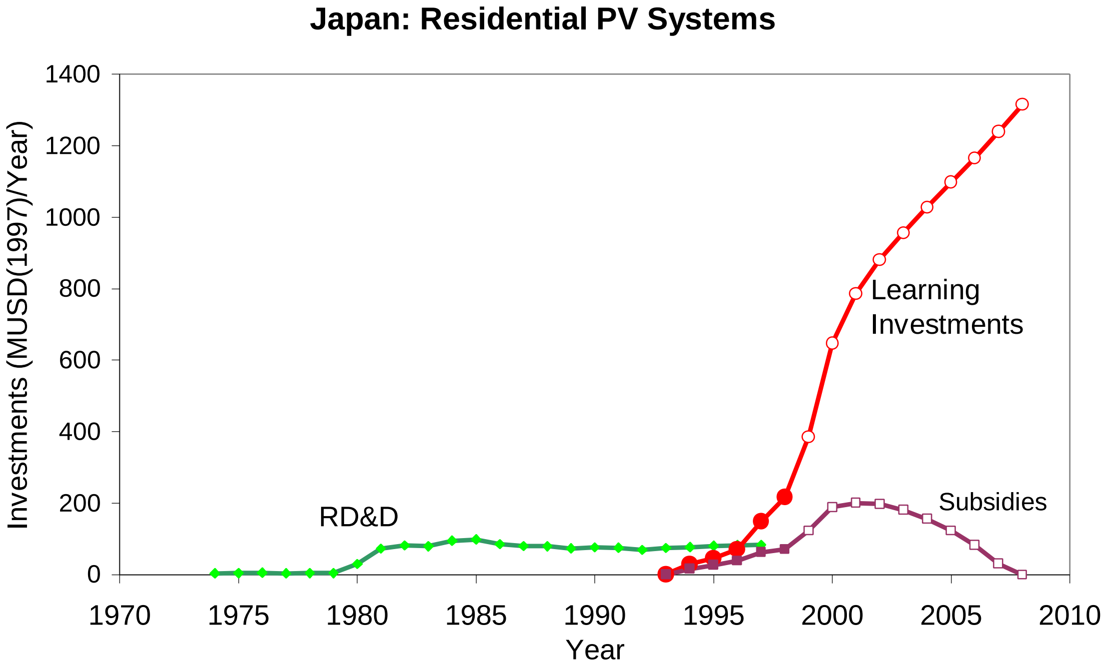
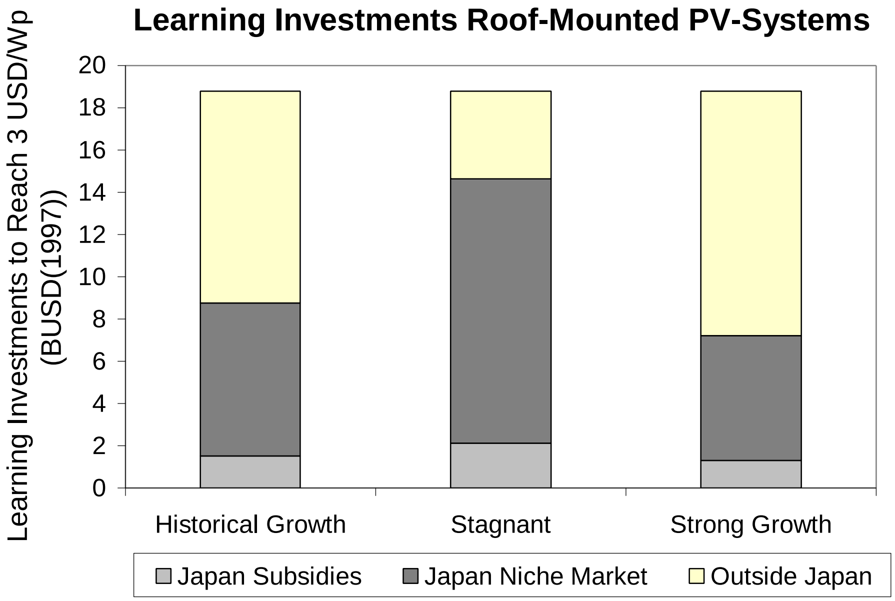


Figure 6. RD&D expenditures for photovoltaics in Japan and subsidies and learning investments for residential photovoltaic systems in the Japanese PV Roofs programme. Open circles and squares are forecasts for learning investments and subsidies assuming a continuation of the Japanese deployment programme. (Information on RD&D from IEA Statistics)

The ratio between learning investments and deployment subsidies is a measure of the efficiency of the approach chosen for the deployment programme. For the German 250 MW programme this ratio is 3.1 meaning that for each DEM spent by the government the market actors have provided additional 2.1 DEM. This a good ratio, but not high enough for photovoltaics. The Japanese programme uses niche markets with a high willingness to pay and can therefore improve this ratio. If the Japanese programme continue as planned until prices have reached 3 USD/Wp, the ratio between learning investment and subsidies will be 5.7, meaning that for each yen of government subsidies the market actors will have provided additional 4.7 yen.

The total amount of learning investments will be a function of entry point and progress ratio for the experience curve. The entry point for solar heated swimming pools was more then 10 times the cost at break-even, but the technology structural change provided the technology with a very steep experience curve. The low progress ratio led to small learning investments.

The experience curves for wind turbines and photovoltaic systems have very different characteristics. Wind turbines had an advantageous entry point only twice the break-even cost, but high progress ratio. The entry point for the photovoltaic systems lay more than ten times above break even, but the progress ratio is much better than for wind turbines. This is reflected in the ratio between total investments and learning investments. For wind turbines in Germany this ratio was 8 for the learning period 1989-1998. The ratio for the photovoltaic systems for the period 1993-2007 is only 1.4. This emphasises the need to activate niche markets with a high willingness to pay in the learning phase.



Figur 7. Sharing of Learning Investments in different scenarios for the world PV market, but assuming an unchanged Japanese programme.

The success of the Japanese programme relies on the continuation of deployment and learning investments on PV markets outside of Japan. Figure 7 illustrates the need to place national deployment programmes in an international context. The forecasts in Figure 6 assumes that PV markets outside of Japan retains their historical growth of 15% per year. Stagnant markets outside of Japan require more learning investments in Japan. Stagnant markets also delay docking to the self-propelling niche markets at 3 USD/Wp and increase the needs for subsidy to reach this docking point. Conversely, strongly growing world markets for PV reduce the demand for learning investments and subsidies in Japan.

5. Conclusion

The case studies suggest that energy technology policies should recognise two distinct phases in the work to bring energy technology to commercial maturity. The first phase needs direct R&D support, but in the second phase the focus should be on providing learning opportunities on the market. Deployment policies are thus a natural continuation of R&D efforts. Direct R&D support is still needed during the second phase to complement industries own R&D, and help to seize any opportunity for technology structural change. However, learning on the market is the driving force for the second phase. National deployment programmes must be put in an international context, which points to the need for concerted actions among governments.

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