THE ESTABLISHMENT OF THE DANISH WINDMILL INDUSTRY – WAS IT WORTHWHILE?

by

Jørgen Drud Hansen, Camilla Jensen

and Erik Strøjer Madsen [†]

CONTENTS:

[†] *Remark:* We wish to thank EM Data in Aalborg for allowing us to make use of their data on windmills in Denmark. We are also grateful to an anonymous referee for helpful comments and suggestions.

1. Introduction

The renewed interest for using wind energy commercially is not more than twenty-five years old. From an experimental stage of turning wind energy into electricity in the 1970s, a new industry for producing standardised windmills gained foothold in the beginning of the 1980s and since then it has developed rapidly through the 1980s and the 1990s. The Danish innovators of the new windmill technology have been the pioneers behind this development, and Denmark has succeeded in acquiring a first mover advantage on the world market. This position has been maintained and at present Denmark satisfies more than half of the world market's demand for windmills.

There are at least two reasons for this pioneering position of the Danish windmill industry. First, Denmark is by nature very 'abundant' in wind energy due to its geographical position at the nexus between the Gulf Stream and the European continent. The windy climate makes given technologies of windmills more productive. Secondly, the production of electricity from wind power has been subsidised by state aid schemes among which the most important one has been a price guarantee per produced kWh (kilowatt-hours) to the owners of windmills (Morthorst, 1999). These subsidies have made production of electricity from windmills profitable for private investors and hence competitive on the market for electricity produced by fossil fuel.

Although the public subsidies to produced electricity from wind power in Denmark have been motivated by environmental concerns over the emission of carbon dioxide (CO_2) from power plants using fossil fuels, the subsidies have resulted in the development of a new industry with a strong export performance. The development of the windmill industry thus illustrates an infant industry strategy where state aid in the upstart phase results in a build up of an internationally competitive industry in the long run. This is the Mill's test of an infant industry strategy (Kemp, 1960). However, a precondition for a successful outcome of such a strategy is the existence of dynamic economies of scale or learning-by-doing within the industry so that the initial infant costs could be paid back later. This is the Bastable's test of an infant industry strategy (Kemp, 1960). The purpose of this paper is to discuss, analyse and evaluate the welfare effects of the Danish policy measures for the windmill industry in order to conclude whether the intervention passes both the Mill's and the Bastable's tests.

The paper is organised as follows. Section 2 introduces the available data on the remarkable development of the Danish windmill industry and presents the evidence of learning-by-doing in this industry. This section is based on the results of a previous analysis of the authors of the technological development in the windmill industry in Denmark. Section 3 gives an evaluation of the costs and benefits in an infant industry perspective and section 4 concludes the paper.

2. Learning-by-doing in the windmill industry

The section begins with a presentation of the data for the Danish windmill industry followed by estimations of the size of the learning effect. See Madsen et al. (2002) for a detailed survey of the empirical literature on learning-by-doing .

The data

The primary political objective of producing windmills is to increase the supply of electricity from renewable sources. The policy was a response to the first energy crisis in the beginning of the 1970s, and from the late 1970s an actual market for windmills emerged making a larger scale of production possible. The data used in this study is obtained from the Danish Wind

Turbine Manufacturers' Association in Copenhagen and from EM Data in Aalborg. The Danish Wind Turbine Manufacturers' Association yearly publishes data on production and sales of Danish windmills in "Windpower Note", whereas EM Data conducts a survey among Danish windmill investors collecting information on investment expenditure and first year production.

Table 1 illustrates the yearly production of windmills in Denmark since 1983 measured either by the number of produced windmills or by total effect measured in MW (megawatt). The effect in MW measures the capacity defined as the produced quantity of electricity per hour under circumstances of optimal wind. At very low wind speeds, the windmill goes out of production and also at high wind speeds production is discontinued to protect the mill from breakdown. Hence optimal wind conditions exist for an interval of wind speed where the windmill produces at its maximum effect.[1] Measured by effect, the annual production of windmills has increased from 117 MW in 1984 to 1900 MW in 1999. The average effect of a windmill has increased from 31 kW in 1983 to 698 kW for windmills sold in 1998. This fact points at a trend in the underlying technologies resulting in production of larger and larger windmills.

Beside these annual data, this study has access to a micro data set with investment and production information for a sample of 833 new windmill instalments. EM Data in Aalborg conducted the sample in the period from 1980 to 1999, and it is a representative sample of prices of new windmills in Denmark. Column 5 in Table 1 lists the average real price, i.e. investment expenditure on the purchase of a windmill with a certain capacity, quoted in kW. It appears from the table that price per unit capacity has fallen to below half the price per unit

[1] The technology has improved during the investigation period so that the interval of the optimal wind has increased. Hence, for given effect new vintages of windmills produce more electricity during a year compared to older vintages for given conditions of wind.

capacity of a mill purchased back in 1981. The last column in Table 1 shows the export share of Danish windmill production expressed in turnover. For most of the years the export share is above 70 % but slumped to below 25% in 1988 when the industry was hit by a temporary recession possibly because the market was slow to respond to the introduction of larger windmill sizes.

Table 1 - *Production, effect and prices for Danish windmills, 1983 – 1998*

The substantial fall in the price points to a strong technological progress in the sector. From the following reported results of estimations it appears that the development is consistent with a hypothesis of endogenous growth of productivity through learning-by-doing. Basically, it is the firm or the plant that generates experiences through its day-to-day operations. These learning effects may be internal or external depending on whether the firm is capable of keeping knowledge about its production for itself or the knowledge diffuses to its competitors.

The following empirical analysis estimates the total learning effect at the industry level no matter whether it is a result of firm-specific learning or a result of knowledge spillovers between the firms. The Danish windmill industry consists of a limited number of producers, as the four biggest firms produce more than 90% of the total production of windmills in Denmark. The producers use nearly the same technology and the firms operate in an industrial cluster drawing on the same pool of highly skilled labour and having available the same public-sector facilities. It is therefore reasonable to assume that the knowledge spillovers among the firms are significant, i.e. that the learning process reflects external dynamic scale economies. Based on this premise, learning is related to the development of the whole industry and we therefore explain the experience accumulation in the industry by the total cumulative production in the industry.

Estimation of the learning effects

The basic relation between production costs and cumulative production is usually specified by the following dynamic cost function:

$$c_t = \alpha Q_{t-1}^{\beta} \quad ; \alpha > 0, \ \beta > 0 \tag{1}$$

where c_t is the production costs per unit of output in period t, Q_{t-1} is the lagged cumulative output, " is a scale parameter illustrating the unit costs of producing the first unit and $ a parameter for the learning elasticity i.e. the percentage decrease in unit costs by one percentage increase in lagged cumulative output. Previous empirical studies of the learning effect typically find a learning elasticity around –0.20. This implies a cost reduction of 2% when the cumulative production increases by 10%, see for example Wright (1936), Liberman (1984), Gruber (1992), Irwin and Klenow (1994), Mishina (1999) and Benkard (1999).

The development of still larger windmills is an integrated part of the observed productivity improvements, and the fall in price per kW might thus be caused both by process innovation (productivity improvements in the production of a given type of windmill) and by product innovation (production of new, larger and more efficient mills). The set of micro data for the sample of 833 windmill installations allows us to analyse how the two types of technological innovations have affected the historical development of the price of a windmill. In a previous study by the authors (Madsen et al., 2002), the productivity development has been analysed in further detail. To pick up also the price effect from larger and more efficient mills the following logarithmic transformation of an expanded version of equation 1 has been used:

$$\ln P_{i,t} = \ln\alpha + \beta\ln N_{t-1} + \delta\ln E_{i,t} + \gamma\ln A_{i,t} + \varphi\Delta N_t + \mu XS_t + \lambda t + \varepsilon_{i,t} \qquad (2)$$

where $P_{i,t}$ is the total price or investment expenditure for windmills in project i delivered in period t, N_{t-1} is the accumulated experience, $E_{i,t}$ denotes the installed effects of windmills in project i, $A_{i,t}$ is the number of windmills in project i (note that for most observations A=1). The investment expenditure on a windmill is expected to rise less than proportional with the size of the mill since windmills with larger effect reflect better technology, i.e. $0<\delta<1$. Also, the investment expenditure is expected to rise less than proportional with the number of mills in the park since it is reasonable to expect that a discount is given when several mills are purchased at the same time, i.e. $0<\gamma<1$. To allow for economies of scale in production of windmills the size of production in the present period ΔN_t is included as an independent explanatory variable. According to the product life cycle theory learning may be stronger when sales are targeted at the home market instead of export markets, because of stronger interaction between users and producers that are located in proximity (Irwin, 1998). To test for this effect the annual export share of the industry XS_t is included in the estimation. Finally, a time trend t is included to capture the exogenously given productivity growth rate, and the last variable $\varepsilon_{i,t}$ is a random, normally distributed error term.

Since no data is available on the unit costs of producing windmills, the price of the mill is used as a proxy for the unit costs.[2] More exactly, the price is specified as the real investment expenditure on the purchase of the mill. This procedure implicitly assumes that the price-cost margin is either constant or at least does not change according to a specific trend during the period of investigation. The learning effect in the individual firm is related to the industry production and not to the production in the firm. If the learning effect is caused by the firm-specific output, the profit-maximizing firm will take this into account by keeping the price-cost margin low in the period where the potential for productivity gains is significant, see Dasgupta and Stiglitz (1988).

The first two columns in Table 2 present the results of the estimated learning model (2) from the aggregate time-series data where the windmill price is the average price per kW in each year as listed in Table 1. However, it is an open question whether learning-by-doing is triggered by production of windmill capacity Q or by number of mills N. We leave it to the estimations to judge between the two alternative specifications and model (2) gives the best fit of the data.

Table 2 - *Estimation of the learning effect with correction for scale in technology, 1983 – 1998*

The estimated parameter for the learning elasticity has the expected sign and is highly significant in the two specifications of the model. The elasticity increases from -0.13 to -0.17 when we measure cumulative production at the industry level with number of windmills

[2] It is quite common to use the price as a proxy for unit costs, e.g. when estimating learning curves in other industries. See for example Gruber (1992) and Irwin and Klenow (1994) for estimations of learning curves in the semiconductor industry.

instead of their capacity due to the change in technology over the period with more than a tenfold increase in the average size of the installed windmills.

The time-dependent growth in productivity is significant and 2.66% per year in model 2. The level of the actual production within the industry has a negative but not significant effect on the price of mills, so no significant economy of scale at the industry level is identified. The export share has a significant positive effect on the price of windmills. This is consistent with the assumption that learning is associated less with sales to distant buyers in export markets. However, alternative explanations cannot be ruled out such as a higher price-cost margin being charged to foreign buyers to cover for the higher risk or larger sales cost borne by the windmill producers in these markets.

Figure 1 illustrates the development in actual and estimated average windmill price per kW along the cumulative production measured in installed capacity. The estimated price model is only based on the learning effect and a general time trend. The model fits the actual decline in the average price of a windmill in this period very well and a learning-by-doing hypothesis is therefore consistent with the illustrated evidence.

Figure 1 - *Actual and estimated price levels against cumulative production of mills*

The innovation of larger and more efficient windmills is an integrated part of the observed productivity improvements. To take this scale effect into account, the size of the individual mill has been introduced as an explanatory variable of the total mill price in models (3) and (4) where the learning effect is estimated on the total sample of 727 mills. In model (3) the size variable E is very significant with a coefficient of 0.77, implying as expected that the price of a mill increases less than proportional to the size of the mill. Also the coefficient to the number of mills purchased per project A is very significant with a coefficient of 0.95 suggesting a 5% price discount when the purchases of windmills are doubled.

The size of the learning effect falls to –0.11 when correcting for scale in the technology of the mills. However, model (4) uses an alternative way of correcting for scale in technology by estimating a fixed effect model controlling for the heterogeneity in mill technology, not only their size. In this model the learning elasticity increases to -0.135, and it is the preferred model as it has the best fit. The size of the industrial learning-by-doing effect implies a reduction of the windmill price with 0.135% when the cumulative production of windmills increases by 1%.

3. An infant industry perspective

The Danish windmill industry has been heavily subsidised since it emerged around 1980. DØR (2002) estimates that total subsidies paid out amount to more than 4 billion DKK in 2002 prices. The most important instrument has been the introduction of a guaranteed price scheme that obliges the electricity firms to buy 'green' electricity from the windmills, at a price considerably above the price of electricity bought from traditional power stations. The guaranteed price also exceeds the expected unit costs of producing electricity by wind power. The incentive to invest in windmills has furthermore been strengthened by friendly tax rules allowing the revenue for sales of electricity from windmills for individual investors to be tax free up to a specific amount per year. This has stimulated the domestic demand for windmills considerably and because of the accumulated experiences Denmark has obtained a remarkably strong position on the world market for windmills as mentioned above. The establishment of the Danish windmill industry thus seems to make up an example of an infant industry strategy where state aid to a new industry has stimulated production and productivity growth, so the industry has acquired competitiveness in the long term.

In traditional welfare analyses of such infant industry strategies, the welfare effects are assigned to two periods: an infant period where the experiences are accumulated and a mature period where further gains in efficiency are more or less exhausted. In the infant period, short-term social costs exceed that of the social benefits. In the mature period, benefits hopefully exceed costs. The overall assessment therefore depends on the time preference for discounting all costs and benefits to a given time.

However, a precise assessment of all costs and benefits in the case of the Danish windmill industry is not possible. At least two circumstances preclude that. First, the book is not closed yet as the project is still ongoing and the final conclusion might thus be influenced by what happens in the future. Secondly, the main expected welfare effect that the policy makers had in view when they decided to subsidise the windmill industry was the environmental gain of a lower CO_2 emission. An assessment of the specific amount of this benefit seems very difficult because less emission of carbon dioxide is a global benefit.

The main welfare loss is related to domestic allocation effects caused by diverting production of electricity from conventional producers to producers of wind-power-based electricity. This loss consists of the private excess cost of producing electricity by windpower minus the assessed environmental benefits of the displaced amount of fossil fuels in production of electricity by traditional power stations. The main social benefit consists of the trade effects related to the productivity gain which the consumers and producers might benefit of both on the domestic market, but especially on the foreign market because of the trade effects related to the formation of a new export industry.

The private excess cost of production diversion

Let us first disregard environmental effects and only compare the private costs of producing electricity by wind power with the costs of producing electricity by fossil fuels. The traditional power stations are committed to buy electricity from the windmills at a guaranteed high price. This might in principle have a pass through effect on consumer prices leading to lower consumer welfare. However, in this specific case the price effect may be neglected, as an excise duty has been imposed making the consumption price more than four times higher than the price paid to the power stations. This excise duty has been implemented under label, a CO_2 duty, referring to emission of CO_2 from the production of electricity by fossil fuels. To internalise the externality in the consumer price, the size of the excise duty should equalise the size of the environmental damage. However, the excise duty was raised from DKK 100 to DKK 600 per tonnes of CO_2 emission during the 1990s, with various exemptions and differential treatments being introduced. The present level of this excise duty is consequently a dubious indicator of the environmental damage. It is therefore reasonable to assume that the government keeps an eye on the consumer price when the size of the excise duty is determined. The pass through of higher production costs due to the distributional electricity firms' obligation to buy electricity from windmills will be absent or at least modest. The consumer price is therefore treated as exogenously given, i.e. the effect of a guaranteed price for green electricity at producer level for the consumer price is disregarded. This assumption eases the welfare analysis considerably as the subsidising of the windmill industry leave the total quantity of electricity produced unchanged.

The unit costs of producing electricity from wind power and fossil fuels are illustrated in Figure 2.

Figure 2 - *Unit costs of producing electricity by windmills and conventional power plants, DKK per kWh in 1998 prices*

The unit costs in 1998 prices of producing electricity from the traditional power stations are calculated as an average of the prices from the 15 traditional power stations to the distribution firms. In the investigation period, all traditional power stations were publicly owned non-profit firms and hence the price of each firm is assumed to represent unit costs of the firm. In calculating the average price, the capacity (effect) of the 15 industrial power stations is used.[3] It appears from the figure that the real unit costs for producing electricity from fossil fuels decrease in the first years of the period, but the changes are without any trend from 1987 and onwards. It might indicate that conventional production of electricity represents a mature technology, where the growth of productivity is in line with the rest of the economy and hence the long-term real price is constant. The year-to-year fluctuations mostly illustrate fluctuations in the input prices of fuels (coal).

The unit cost of producing electricity by windmills is more complicated to calculate. First, the average price or installation costs of the individual vintage of windmills relative to the expected yearly production of electricity are calculated as reported in Table 1. These installation costs represent sunk costs. During the expected life of the windmill, the owner also incurs recurrent costs (e.g. cost of repair) and fixed recurrent costs (e.g. insurance and land rent). From the data for recurrent costs in a sample of 194 mills the following recurrent cost function is estimated:

$$C = kE^{\mu} A^{\eta} \tag{3}$$

where C denotes the recurrent costs relative to the expected yearly production, E is the installed effect measured in kW and A is the age of the mills. Estimating a logarithmic transformation of (3) gives the following result with t-values in parentheses:

$$\underset{}{\log C} = \underset{(2.53)}{3.51} - \underset{(2.16)}{0.36} \log E + \underset{(1.40)}{0.42} \log A \tag{4}$$

$R^2 = 0.81$ $\quad$ $N = 10$

By using the parameters of equation (4) and the price deflator, it is possible to calculate the profiles of recurrent costs in fixed prices for windmills with effects equal to the average effect of each vintage of windmills. Table A in the appendix shows present value of recurrent costs in fixed 1980-prices for each vintage of windmills, measured relative to the expected yearly production of electricity. Assuming that the duration of the windmill is 10 years or alternatively 15 years, present value of recurrent costs at the time when the mill is installed is calculated using a real rate of interest at 3% per year or alternatively at 5% per year.

---

[3] The 15 power stations cover more than 80% of the total domestic supply of electricity.

These present values of recurrent costs are then added to the average price of the mill for each vintage. The total present values of all costs are subsequently transformed to unit costs of production of electricity for the assumed lifetime of the mills. Table B in the appendix shows the results of this calculation together with the unit costs of producing electricity by fossil fuels.

It appears from Figure 2 that accumulation of experience and development of the technology within the windmill industry have narrowed substantially the excess costs for producing electricity by windmills compared to the unit costs of producing electricity using traditional technology. Assuming the lifetime of a windmill is 15 years, the unit costs of producing electricity by wind power are seen only to be marginally above the unit costs of production from a traditional power plant at the turn of the century. Taking into account the recent rise in the oil and coal prices, the most recently installed windmills may be competitive today under normal business conditions without state aid (Botterud et al., 2002).

Figure 3 illustrates the cost structure and price settings in the market for electricity in a given year. The price p_0 is exogenously given, i.e. determined by the policy makers' decision about the excise duty. The demand for electricity is illustrated by the DD-curve and corresponding to the market price p_0. The consumption of electricity makes up Q_0, partly delivered from windmills $\overline{Q}_w$ and partly from conventional production $\left(Q - \overline{Q}_w\right)$. Conventional electricity is produced at the unit costs c.[4] The unit costs of producing electricity by the individual vintages of windmills are all above c and the capacity to produce electricity of each vintage is exogenously given by the investment in the past.

[4] In fact, international trade also takes place with electricity as the Danish electricity network is linked to the network in neighboring countries. The trade of electricity has mostly been used to counteract efficiency losses caused by random changes in domestic demand and supply. In the following welfare analysis, we therefore perceive conventionally produced electricity as the relevant alternative to wind-power-produced electricity.

Figure 3 ranks the supply of electricity from the individual vintages of windmills with the newest installed windmills first and as new windmills produce to lower unit costs compared to older ones, the production and unit costs for all vintages of windmills make up a staircase-like curve in Figure 3. The shaded area illustrates the total amount of excess costs for the given year.

Figure 3 - *Price and cost structure at the market for electricity*

For evident reasons, it is not possible to make a full *ex post* assessment of the present value of the excess costs for producing electricity by wind power. The recent vintages of windmills are expected to produce electricity for several years in the future and the unit costs of conventionally produced electricity in future are unknown. It is only possible to make *ex ante* calculations based on assumptions about expectations. Past experience shows that the performance of the windmills is close to the technical speculations of their productivity. The real price of conventionally produced electricity has been quite stable, and it seems reasonable that this also will apply in the future. These facts invite the following *ex ante* calculations.

The perceived present value of the expected yearly loss at the time of installation for each generation of windmills is calculated in two steps. First, the yearly flow of losses for each generation of mills is calculated as the excess unit costs times the expected yearly production, which is reported in Table 3, column 1. Second, the perceived present value of the yearly loss at the time of installation is calculated by discounting back to the time of installation the yearly loss for the whole span of years where the individual generation of windmills is expected to be in use. This gives the results reported in columns 2-5. For example, the loss is less if it is assumed that the lifetime of the mills is 15 years instead of 10 years. It also appears from Table 3 that the loss varies positively with the real rate of interest. Furthermore, the perceived loss for the recent vintages of mills is substantial although the excess unit costs of producing electricity by wind power are modest. This is due to the large capacity and hence large expected production of electricity for the most recent generations of windmills.

Table 3 - *The perceived present value of the loss by producing electricity by wind power*

A simple adding up of present values of losses calculated at the time of installation for all generations of windmills is estimated to be in the interval DKK 2.4 - 5.2 billion, 1998 prices (see Total 1, Table 3). However, the present value of these loses refer to different years as all amounts for a specific generation of windmills have been discounted back to the year of construction of this generation. This might be misleading and to correct for that the last line in Table 3 illustrates present values of losses for all generations up till 1998 discounted front up to 1998. These figures (Total 2) thus relate all amounts consistently to a given year and as the terminal year 1998 is chosen as reference, the losses associated with Total 2 are somewhat greater.

Some caveats

However, this calculation may be too optimistic, as the green subsidy may be bigger than calculated above. First, the marginal costs of producing electricity by conventional power stations may be considerably lower than the average unit costs reported in Figure 2. The establishment of windmills and the implementation of a high excise duty on the use of electricity have resulted in a substantial excess capacity for the traditional power stations. At least in the short run, the calculation of excess costs for new windmill projects should be based on total unit costs for producing electricity by wind power, but only marginal costs for traditional power stations. Second, the traditional power stations have also the obligation to supply electricity on days without wind. The production capacity of traditional power stations will therefore not even in the long run be reduced by the average production from windmills, and hence, the reported average unit costs of conventionally produced electricity are higher than it would have been without the obligation to absorb the volatile production of electricity from windmills. Third, the traditional power plants also have the obligation to pay the costs of connecting the windmills to the transmission network, which can be quite expensive for mills off shore or far away from the transmission wires. Fourth, the price of electricity on the international market is often much lower than the average price from traditional power stations. In such cases it does not show 'good merchantship' to buy electricity from windmills instead of utilizing attractive offers at the international market. (On the other hand, access to the international market mitigates the above mentioned excess capacity problem as insufficient capacity of traditional power plants at calm days is possible to overcome by importing electricity.)

Environmental issues

As previously mentioned, the subsidising of electricity production by wind power has been motivated by environmental considerations. Especially, that this production mode does not cause emission of CO_2. However, this has been at the expense of a considerable pecuniary loss as shown above. The CO_2 emission from traditional power stations based on coal is in the range 700 - 800 kg CO_2 per Mwh depending on age and technology of the power station (Finansministeriet, 1996). The yearly production of electricity of all generations of windmills for the period 1983 to 1998 is about 3,200 Gwh (Gigawatt hours) as reported in Table 3, column 1. This is equivalent to a yearly reduction of approximately 24 million tons CO_2, assuming that traditional power stations burden the environment with 750 kg CO_2 per Mwh. Table 4 shows the results of a simple calculation of the implicit price of CO_2, by relating the present value of the yearly loss for all generations of windmills to the total saving of CO_2 emission for a period of production of 10 or 15 years respectively.

Table 4 – *The implicit price of carbon dioxide (CO_2)*

As the present value of the yearly loss decreases significantly with the lifetime of the windmills and the saved CO_2 increases, the implicit price of CO_2 is more than halved when the lifetime of the windmills increases from 10 to 15 years. Still, the implicit loss by producing electricity by the more expensive windmills instead of using the traditional power plant is still low compared to the CO_2 tax, which the consumers and the industry have to pay.

The benefits of acquiring comparative advantages

The possible benefits for Denmark of having established a new industry with a strong position on the international market is also difficult to assess quantitatively. If a country increases the number of industries where it has comparative advantage in principle two effects on welfare might be discerned. First, more export industries tend to improve real factor remuneration for all sectors in the economy, even in the case where all industries operate under no entry barriers and hence zero pure profit (Krugman, 1987). However, a quantitative assessment of this positive effect on the Danish welfare of the appearance of the windmill industry will be pure guesswork. Second, if entry barriers exist, welfare may be improved through higher factor remuneration due to above profit in the industry.

An investigation made by DØR (2002) of the wage and profit rates in various sectors illustrates that employees in the windmill industry in 1999 obtain 11 to 12% higher wage rate compared with employees with similar characteristics in other industries. On the other hand, the return on capital in the windmill industry is reported to be about 9% below the average rate of profit in non-environmental industries. The latter result can be extremely sensitive to the specific year as a similar investigation for 1997 points to an excess profit rate in the windmill industry in that particular year (DØR, 2002). It should also be noted that if the learning effect is firm-specific (which has been disregarded in the present paper) the actual price-cost margin and hence the reported profit rate may be kept low in the infant period to stimulate output and further learning.

The share prices at the stock exchange of firms producing windmills may give some indication of the present value of the expected future profit of production of windmills, and as this is a stock variable it allows for a comparison with the calculated present value of losses in Table 3.

Table 5 - *Estimated market value of the four largest Danish producers (million DKK)*

The two largest firms producing windmills in Denmark are listed on the Danish stock exchange, and their combined market value in the period 1999-2002 was on average 27 billion DKK. These calculations are shown with Table 5. The market value of the four largest producers is here estimated to total on average 31,245 million DKK. As the capital paid-in by shareholders and the profits retained from previous years make up less than DKK one billion (not shown), the gain for the shareholders has been significant.

However, two caveats should be kept in mind for the results in Table 5. First, as appears from the Table the market values of the firms vary considerably depending on the year of observation and are very sensitive as to whether the market in general is a ‘bull’ or a ‘bear’ market. Secondly, the firms are partially owned by foreigners and a part of the benefit might go to foreign citizens (DØR, 2002). There is no information available about the share prices at which this transfer of ownership from Danish to foreign citizens has taken place. It might also be argued that such ‘distributional game’ associated with the internationalisation of financial markets should not blur the analysis of the social welfare effects of the policy.

Weighing the costs and benefits

The above calculations of losses and benefits hence only allows for a tentative set of conclusions. The reported present value of losses in Table 3 neither takes into account tax distortion effects, any possible negative welfare effects associated with paying out subsidies (such as distortions and administrative cost) nor environmental effects. The tax distortion effect roughly increases the loss by 1 billion DKK in 1998 prices (DØR, 2002). Distortions associated with the administration of the subsidy scheme are assumed at most to amount to one quarter of total subsidy payments. Hence additional cost on top of the productive distortions estimated with Table 5 amount to 2 billion DKK at most.

The environmental benefit has only been discussed tentatively in this paper. But the productive distortions should in principle be weighed also against the benefit of reducing the negative environmental externality associated with CO_2 emission. But attempts to estimate the value of the environmental benefit would depend heavily on political preferences.

Even without including the environmental benefit into the present analysis, it is shown that the market valuation of the firms in the stock market is much larger than even the most pessimistic calculation of the present values of the losses. Only a tiny fraction of the market value may be traced back to paid-in money from the shareholders (around 1 million DKK). The overwhelming part reflects present values of expected future excess profits and despite all the uncertainties the weighing of costs against benefits points to a positive welfare effect of the policy in excess of 20 billion DKK.

In this assessment no weight has been given neither to environmental benefits nor to the general effect on the factor remuneration for the whole economy related to the emergence of a new export industry.

4. Conclusions

To be deemed successful, an infant industry policy should pass two tests: the Mill's test and the Bastable's test, Kemp (1960). The Mill's test says that a successful infant industry strategy should improve the international competitiveness of the industry. It is evident that the case of the Danish windmill industry fully lives up to this criterion as most of the world's exported production of windmills comes from Denmark today. The Bastable's test requires that the welfare loss in the infant period should be paid back in the mature period taking into account also the time preference. The rough calculations in the previous section also point to a fulfilment of this criterion although the conclusions are tentative and geared with some uncertainty.

However, the assessment of an infant industry strategy should also address the question of the specificity of the chosen instruments (see, for example, Mikic, 1998). The measures or instruments used should be selected so that the net welfare gain is optimised. In the Danish case, the instruments used have stimulated the production of windmills without decoupling the internal price level for windmills from the international price level (as a tariff would have done) and, as argued in the previous section, the consumers' demand for electricity has not been distorted by the distributional firms' obligation to buy electricity from the windmills because of the excise duty. The chosen instrument type therefore seems to be efficient from a welfare point of view. However, the analysis does not reveal whether the same positive results could have been obtained at a lower level of subsidization.

Distributional implications have also been neglected in the evaluation of the policy. The possibility of raising a windmill has been reserved to special areas through the legislation for land use. When this legislation was approved, the owners of those areas got a substantial windfall gain because raising a windmill from a private point of view is a very lucrative investment. But non-owners of windmills in the areas eligible for raising windmills suffered a substantial windfall loss. Close neighbours to a windmill might tolerate a reduced quality of the landscape and noise from the windmill.

The establishment of the Danish windmill industry was a result of Danish political concerns about the emission of carbon dioxide from producing electricity from fossil fuels. The primary objective of the policy was to live up to environmental ambitions, but the performance of the industry nevertheless shows an example of a successful infant industry strategy. However, it happened despite being unanticipated among policymakers at the time the policy was decided. The case therefore demonstrates a fundamental problem with infant industry policy. It is nearly impossible for the policy makers *ex ante* to identify potential 'winners', which might appear if suitable subsidies or measures of protection are implemented. It is much easier to forward opinions about rationality of a specific infant industry policy from a know-all-attitude of *ex post* experiences.

References

Benkard, C. L. (1999): “Learning and forgetting: the dynamics of aircraft production”, *NBER Working Papers*, no. 7127, Massachusetts: National Bureau of Economic Research.

Botterud, A., A.K. Bhattachayya and M. Ilic (2002): ‘Future and spot prices – an analysis of the Scandinavian electricity market’, Proceedings of the North American Power Symposium 2002, October 14-15, 2002 in Tempe, Arizona.

Danish Wind Turbine Manufacturers’ Association (1999): “Danish wind energy 4th quarter 1998", *Windpower Note*, no. 22, April 1999.

Dasgupta, P. and J. Stiglitz (1988): “Learning-by-Doing, Market Structure and Industrial and Trade Policies”, *Oxford Economic Papers*, 40 (2): 246-268.

DØR (2002): *Dansk Økonomi*, forår 2002, Kapitel 3, Det Økonomiske Råd, København.

Finansministeriet (1996): *Miljøregulering af el og kraftvarme produktionen*, udredning fra Finansministeriet, København.

Gruber, H. (1992): “The Learning Curve in the Production of Semiconductor Memory Chips”, *Applied Economics*, 24 (8): 885-894.

Irwin, D.A. and P.J. Klenow (1994): “Learning-by-Doing Spillovers in the Semiconductor Industry”, *Journal of Political Economy*, 102 (6).

Irwin, D.A. (1998): "Did Late Nineteenth Century U.S. Tariffs Promote Infant Industries? Evidence from the Tinplate Industry", *NBER Working Paper*, No. 6835, Massachusetts: National Bureau of Economic Research.

Kemp, M.C. (1960): "The Mill-Bastable Infant Industry Dogma", *Journal of Political Economy*, 68: 65-67.

Krugman, P. R. (1987): "The Narrow Moving Band, the Dutch Disease, and the Competitive Consequences of Mrs. Thatcher: Notes on Trade in the Presence of Dynamic Scale Economies", *Journal of Development Economics*, 27: 41-55.

Liberman, M. B. (1984): "The learning curve pricing in the chemical industries". *Rand Journal of Economics*, 15: 213-228.

Madsen, E.S., C. Jensen and J. D. Hansen: (2002): "Scale in Technology and Learning-By-Doing in the Windmill Industry", *Journal of International Business & Entrepreneurship*.

Mikic, M. (1998): "International Trade". London: Macmillan Press Ltd.

Mishina, K. (1999): "Learning by New Experiences: Revisiting the Flying Fortress Learning Curve". In (eds. N. R. Lamoreaux, D. M. G. Raff and P. Temin) *Learning by doing in markets, firms and countries*. National Bureau of Economic Research: US.

Morthorst, P. E. (1999): "Capacity development and profitability of wind turbines", *Energy Policy*, 27: 779-787.

Wright, T.P. (1936): "Factors Affecting the Cost of Airplanes", *Journal of the Aeronautical Sciences*, 3: 122-128.

Tables and Figures for insertion in the text

Table 1 - *Production, effect and prices for Danish windmills, 1983 – 1998*

Year	No. of mills	Effect in MW	Effect per mill in kW	Price per mill in DKK/kW, 1980-prices	Export share
1983	1279	40	31	6846	0.28
1984	1694	117	69	6287	0.93
1985	3812	243	64	5598	0.91
1986	2246	212	94	5176	0.84
1987	767	88	115	4845	0.59
1988	597	102	171	3978	0.23
1989	754	136	180	4082	0.38
1990	723	162	224	4323	0.54
1991	778	166	213	4482	0.54
1992	712	165	232	4343	0.71
1993	689	210	305	4142	0.83
1994	1144	368	322	3882	0.88
1995	1530	574	375	3369	0.87
1996	1360	726	534	3433	0.69
1997	1644	968	585	3328	0.69
1998	1742	1216	698	3191	0.74

Notes: Calculations in fixed prices are based on the deflator for gross factor income for the period 1983-93 and gross domestic product for 1993-98.

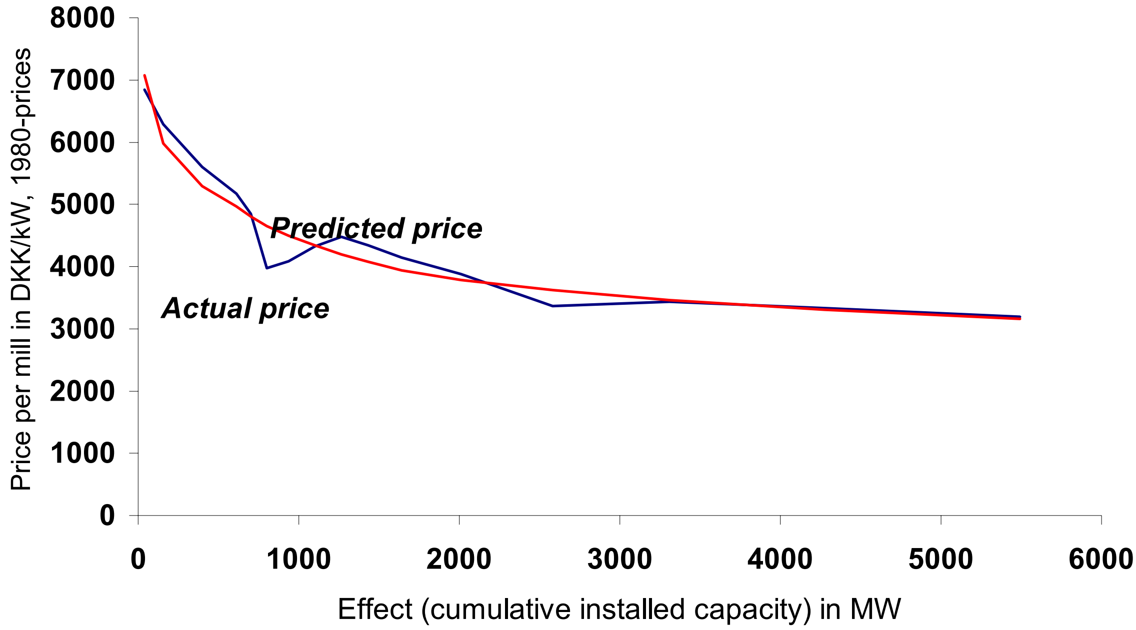
Source: Danish Wind Turbine Manufacturers' Association (1999): "Danish wind energy 4th quarter 1998", *Windpower Note*, no. 22, April 1999. EM Data, Aalborg.

Table 2 - *Estimation of the learning effect with correction for scale in technology, 1983 –1998*

	Dependent variable: log P_t			
	P_t: Average mill price per kW		P_t: Total mill price per project	
	Model 1	Model 2	Model 3	Model 4
Intercept	10.8501**	13.2500**	9.3830**	-
	(0.5854)	(0.4171)	(0.2323)	
Log Q_{t-1}, cum. prod.	-0.1305**	-	-	-
	(0.0306)			
Log N_{t-1}, cum. prod.	-	-0.1713**	-0.1109**	-0.1353**
		(0.0400)	(0.0288)	(0.0383)
Log E_i, mill capacity	-	-	0.7775**	-
			(0.0137)	
Log A_i, mills per project	-	-	0.9580**	0.9699**
			(0.0274)	(0.0261)
Log ΔQ_t, actual prod.	-0.0484	-	-	-
	(0.0375)			
Log ΔN_t, actual prod.	-	-0.0495	-0.0006	0.0191
		(0.0379)	(0.0179)	(0.0244)
XS_t, Export share	0.2881**	0.2790**	0.0994*	0.1946*
	(0.0820)	(0.0910)	(0.0478)	(0.0515)
t, time trend	-0.0086	-0.0266**	0.0099**	-0.0171*
	(0.0090)	(0.0059)	(0.0038)	(0.0055)
R2 (adjusted)	0.9478	0.9403	0.9383	0.9525
No. of observations	15	15	727	727

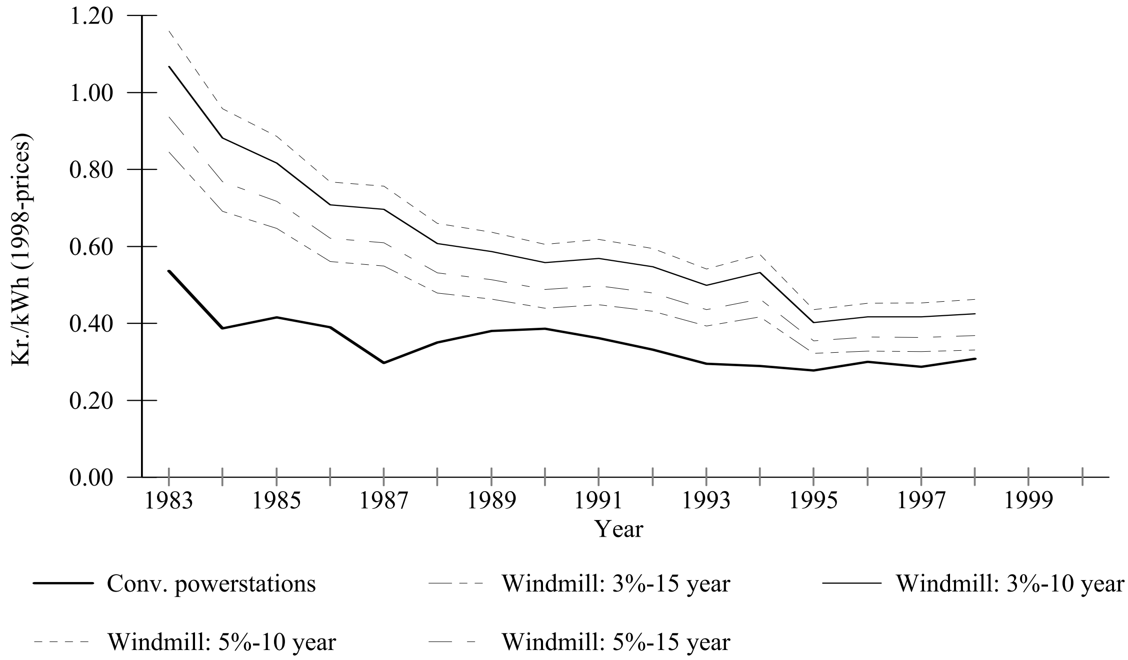
Notes: Numbers in brackets are standard error of the coefficient.
* denotes that the estimated coefficient is significant at the 5% level, ** at the 1% level.

Figure 1 - *Actual and estimated price levels against cumulative production of mills*



Source: Danish Wind Turbine Manufacturers' Association (1999): "Danish wind energy 4th quarter 1998", *Windpower Note*, no. 22, April 1999. Table 1.

Figure 2 - *Unit costs of producing electricity by windmills and conventional power plants, DKK per kWh in 1998 prices*



Source: Own calculations reported in the Appendix Tables A and B for producing electricity by wind power and calculations based on statistics from Danske Energiselskabers Forening for producing electricity by fossil fuels.

Figure 3 - *Price and cost structure at the market for electricity*

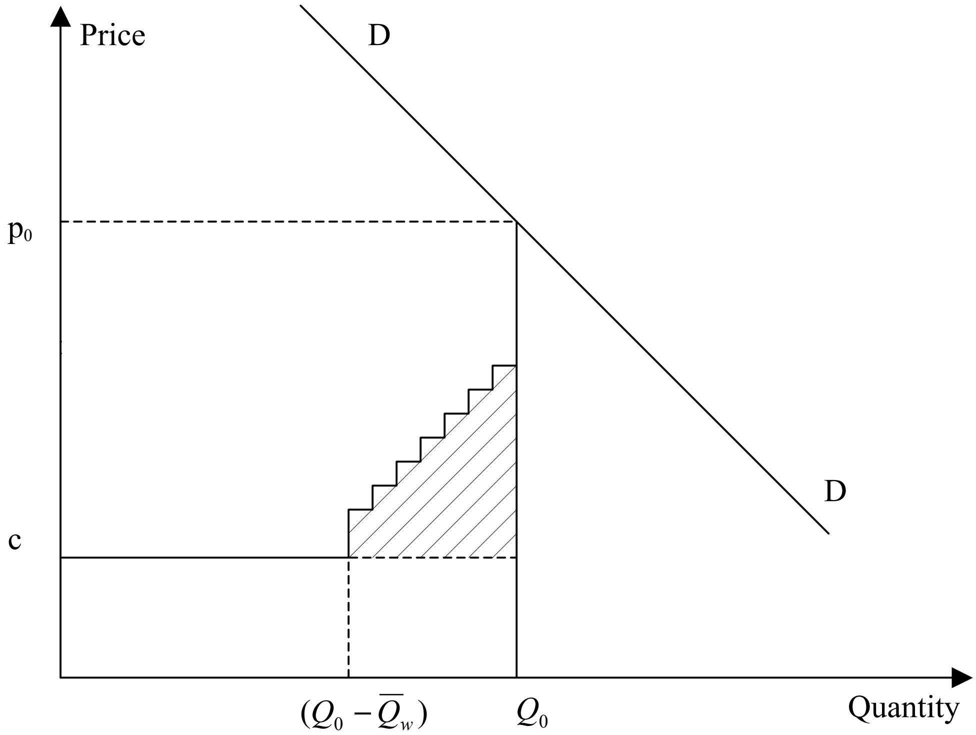


Table 3 - *The perceived present value of the loss by producing electricity by wind power*

Generation of Windmills	Expected production in million kWh/ year	Present value of the yearly loss million DKK, 1998-prices			
		10 years		15 years	
		3% interest	5% interest	3% interest	5% interest
1983	38	173	183	141	158
1984	15	61	64	53	57
1985	46	156	166	126	143
1986	67	183	196	138	162
1987	66	224	233	198	213
1988	154	337	367	236	289
1989	132	232	260	131	183
1990	180	263	304	114	189
1991	164	290	324	169	231
1992	101	186	205	121	154
1993	69	120	132	81	101
1994	107	221	239	162	193
1995	243	259	297	128	196
1996	519	518	613	175	347
1997	649	715	829	306	511
1998	655	664	793	185	421
Total, 1	-	4,601	5,207	2,463	3,548
Total, 2	-	6,167	8,591	3,167	5,670

Notes: Total, 1 – simple adding up of present values of loss without discounting. Total, 2 – adding up present values of loss all discounted back to 1998.

Source: Own calculations based on Table 1

Table 4 – *The implicit price of carbon dioxide (CO_2)*

	Real interest rate	DKK per ton, 1998-prices
10 years	3 %	190
	5%	217
15 years	3%	69
	5%	97

Notes: The total production of electricity per year is assessed to 3,213.5 Gwh corresponding to a reduction of CO_2 of 24,101,250 tons for a 10-year-period or 36,151,875 for a 15-year-period. The implicit price is the present value of the yearly loss relative to the CO_2 saving.

Source: Table 3 and Finansministeriet (1996).

Table 5 - *Estimated market value of the four largest Danish producers (million DKK)*

	Vestas[1]	***NEG Micon***[1]	***Bonus***[2]	***Nordex*** [2]	***Total***
1999	3,635	1,917	2,335	1,164	9,051
2000	14,011	3,750	2,106	1,482	21,349
2001	45,056	10,767	4,367	1,590	61,780
2002	22,633	5,823	na	na	-
Today (3rd quarter, 2002)	10,949	4,300	na	na	-
Average	**21,333**	**5,564**	**2,936**	**1,412**	**31,245**

Notes: 1:These firms are listed on the Copenhagen Stock Exchange and the market value is calculated as the share values each year (primo) times the number of shares. The average is a simple average for the period 1999-2002.

2:Market value is estimated by multiplying the annual result with a price-earning ratio of 15. The average is a simple average for the period 1999-2001. Note that Nordex was incorporated into the German-owned Nordex Group in 2000 and floated on the Frankfurt Stock Exchange.

Source: Historical share quotations from the Copenhagen Stock Exchange and Annual Reports of the four firms.

Appendix

Table A. Present value of recurrent costs for each vintage of windmills and the average mill price, øre per kWh in 1980 prices.

	Recurrent costs				Mill price
	10 years		15 years		
	3%	5%	3%	5%	
1983	79	127	71	109	370
1984	59	96	54	82	311
1985	61	98	55	84	282
1986	53	86	48	74	244
1987	50	80	45	68	243
1988	43	69	39	59	212
1989	42	68	38	58	204
1990	39	63	35	54	195
1991	40	64	36	55	199
1992	39	62	35	53	191
1993	35	56	32	48	174
1994	34	55	31	47	189
1995	33	52	29	45	136
1996	29	46	26	40	146
1997	28	45	25	38	147
1998	26	42	24	36	152

Source: Own calculations.

Table B. Unit costs of producing electricity, DKK per kWh in 1980 prices.

	Wind power				Fossil fuels
	10 years		15 years		
	3%	5%	3%	5%	
1983	0.53	0.57	0.42	0.46	0.26
1984	0.43	0.47	0.34	0.38	0.19
1985	0.40	0.44	0.32	0.35	0.20
1986	0.35	0.38	0.28	0.31	0.19
1987	0.34	0.37	0.27	0.30	0.15
1988	0.30	0.32	0.24	0.26	0.17
1989	0.29	0.31	0.23	0.25	0.19
1990	0.27	0.30	0.22	0.24	0.19
1991	0.28	0.30	0.22	0.24	0.18
1992	0.27	0.29	0.21	0.24	0.16
1993	0.25	0.27	0.19	0.21	0.14
1994	0.26	0.28	0.20	0.23	0.14
1995	0.20	0.21	0.16	0.17	0.14
1996	0.20	0.22	0.16	0.18	0.15
1997	0.20	0.22	0.16	0.18	0.14
1998	0.21	0.23	0.16	0.18	0.15

Source: Own calculations reported in Table A and statistics from Danske Energiselskabers Forening for producing electricity by fossil fuels.

Abstract: The paper examines the welfare effects of the Danish subsidies towards the production of electricity from windpower. This policy has been a precondition for the remarkable development of the Danish windmill industry resulting in a dominant position on the world market. The article demonstrates a strong learning-by-doing productivity growth in the Danish windmill industry and it analyses the costs and benefits of this infant industry case. The costs consist of the efficiency loss from diverting production of electricity from using fossil fuels to utilizing windpower. In making up the benefits the environmental damage of using fossil fuels should in principle be taken into account. However, the main benefits are related to the emergence of a new export sector. As the value of the windmill firms at the stock exchange by far exceeds that of the accumulated distorted loss in production of electricity, this case would appear to make up an example of a successful infant industry strategy.

Key words: Learning-by-doing, infant industry, green subsidies

JEL Classification: D2, L5, L6