RESEARCH ARTICLE

Vikings and virtues: a decade of CO₂ taxation

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Abstract

Experience with implementation of CO₂ taxes spans almost a decade in the Nordic countries, and time is ripe for an evaluation of their performance. In contrast to ex-ante forecasts, empirical research can show the extent to which such taxes deliver on the assumptions of economic theory. A survey of the existing literature shows that there are currently 20 ex-post studies of the full or partial effects of CO₂ taxes. Evaluations are complicated by frequent changes in tax rates, widespread exemptions and the ‘too many variables’ problem. Attempts have been made to deal with these problems by using a variety of approaches and research techniques, some more advanced than others. On balance the studies appear to show that emissions have been curbed when compared to business-as-usual forecasts, while absolute CO₂ reduction remains the exception. Among the Nordic countries, Denmark’s scheme, which combines taxes with subsidies for energy efficiency, seems to have attained the most marked results, although the achieved reductions also reflect the higher carbon content of the Danish energy sector. The evaluations differ considerably in scope, approach and methodology. Methodological issues connected with ex-post evaluation are considered. An adequate evaluation of the impact of the CO₂ taxes, in both environmental and economic terms, will require the establishment of comprehensive panel databases of energy consumers.

Keywords: Climate policy; CO₂; Energy; Environmental taxes; Ex-post evaluation; Implementation

1. Introduction

The Nordic tradition for taxing energy, natural resources and pollution dates back to the 1970s, but has been intensified during the last decade with the introduction of a number of new and innovative environmental taxes. Some of these taxes have now become subject to review and assessment, allowing more to be learnt about their environmental and economic effects (see Andersen *et al.*, 2001). The focus here will be on CO₂ taxation.

The first tax on CO₂ emissions was introduced in 1990 in Finland after a proposal from the Conservative Minister of the Environment, Ms. Pietikäinen. Norway and Sweden introduced similar taxes in 1991, while Denmark followed suit in 1992. Only Iceland has no CO₂ tax. The taxes differ considerably as

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regards rates, tax base and exemptions, and it would be misleading to speak about a specific ‘Nordic model’ for carbon-energy taxation, as they are all adapted to national conditions affecting energy supply and policy (Malaska *et al.*, 1997; Ekins and Speck, 1999).

Nominal tax rates are currently the highest for Danish households. Sweden and Norway have the highest rates for industry; however, Norway applies the high-rate to the offshore oil and gas industry while certain industrial processes are exempted. Denmark taxes industrial heating at the same rate as household heating. All four countries have special arrangements for energy-intensive companies. For a detailed account of the tax structures, see CEU (1998) and the Nordic Council of Ministers (1999). It can be observed that all the taxes have been set according to pragmatic considerations, and not on the basis of a valuation of externalities.

The energy supply structure in the Nordic countries varies (see Table 1). While Norway has large hydropower resources, Denmark relies mainly on fossil fuels, in particular coal. Nuclear power is used in Sweden and Finland; however, these countries use more fossil fuels than Norway. Iceland has a huge and unexploited reserve of renewable energy, but uses fossil fuels for its fishery and transport sectors.

Table 1. CO₂ emissions and share of fossil fuels of total energy supply, 2000 (source: UNFCC and OECD)

	Population (millions)	Per capita CO ₂ emissions (tonnes)	Share of fossil fuels (% total energy supply)
Denmark	5.33	9.9	89
Finland	5.18	12.0	76
Iceland	0.28	8.7	37
Norway	4.56	9.0	47
Sweden	8.88	6.3	68

Per capita CO₂ emissions are highest in Finland and lowest in Sweden. Energy consumption is lowest in Denmark; however, the Danish dependence on fossil fuels leads to per capita emissions exceeding those of more energy-consuming countries like Norway and Sweden.

Since the CO₂ taxes have now been in place for almost a decade, it would appear timely to evaluate their effects by ex-post methods. Extensive assessments and evaluations of the CO₂ taxes have been carried out in Denmark, Finland, Norway and Sweden. In our review of the literature 68 such studies have been identified, most of them ex-ante assessments based on various economic models. Of the ex-post evaluation studies, approximately 20 draw to some degree on the historical data concerning the response to the taxes.

According to the OECD, ex-post evaluations may produce more reliable information on the effects of taxes than theoretical ex-ante modelling in which many assumptions about specific scenarios must be made (OECD, 1997). Nevertheless, the methodology and rigour of ex-post studies can be seen to vary substantially. Many are simply partial ex-post evaluations addressing specific sectors or covering a specific period of time. A review of the group of ex-post evaluation studies follows.

2. Findings and observations on trends in CO₂ emissions and the effects of CO₂ taxes

The information presented below for Norway, Sweden, Finland and Denmark is summarized in Tables 2 and 3.

Table 2. Trends in CO₂ emission

	CO ₂ emissions (tonnes)	CO ₂ emissions (tonnes)	Percentage change	
	1991	2000	Decrease	Increase
Norway	33.0	41.0	–	24%
Sweden	56.7	55.9	1.4%	–
Finland	62 (1990)	–	0%	–
Denmark	–	52.8 ^a	12 % ^b (over 1990)	0% ^a

^a UNFCCC.^b Corrected for electricity exports (Danish government).Table 3. Effects of CO₂ taxes as identified by selected studies with differing focus

Study	Country	Period	CO ₂ Reductions	
			Reductions	Role of CO ₂ tax
ECON (1994, 1997)	Norway	–	–	30%
NUTEK (1994)	Sweden	1990–1994	–	3–5%
Naturvårdsverket (1995)	Sweden	1987–1994	–	19% ^a [3–5% ^b]
Shopley and Brasseur (1996)	Denmark	–	20%	Not identified
Clasen (1998)	Denmark	–	–	Significant
Ministry of Finance (1999)	Denmark	–	–	5% reduction

^a Excluding transport sector.^b Including transport sector.

2.1. Norway

Norway has a high nominal tax rate; however, the majority of industries are exempt. As a result just 60% of Norwegian CO₂ emissions are taxed.

Norwegian CO₂ emissions have increased from 33 million tonnes in 1991 to 41 million t in 2000. The main reason for this development is increased activity in the offshore oil and gas industry. Correspondingly, the main impact of the Norwegian CO₂ tax is found in this offshore industry where, according to research by the ECON (1994, 1997), CO₂ emissions were 30% lower per unit of production than would have been so without the tax regime. This finding is based on a detailed assessment of technological responses to the tax. Experts focusing on the offshore petroleum sector as a whole have identified four measures in particular which have helped reduce emissions by 4 million t, representing approximately 10% of the national emission (Lindeberg, 1996). The same experts further illustrate a marked decoupling, in that in a period where Norwegian oil production increased by 55%, CO₂ emissions increased by only 18%, due largely to the tax (see Table 6). ECON also identified a number of measures taken in the offshore sector to reduce CO₂ emissions and calculated which were profitable as a direct result of the tax. Despite many of the measures being profitable even without the tax, the tax focused attention on emissions reductions in general.

A comprehensive analysis of CO₂ emissions in the household and industrial sectors has been carried out by Statistics Norway (Larsen and Nesbakken, 1997). The approach used was a counterfactual analysis in which a baseline without tax was constructed and compared with actual developments. A macroeconomic model was combined with a general-equilibrium model for the transport sector. The study, covering the years 1991–1993, demonstrates that household sector emissions declined by 3–4%. Not surprisingly, the decline within the industrial sector was merely 0.5%, due to the many exemptions.

2.2. Sweden

Sweden's CO₂ tax has undergone some major fluctuations (Stern and Löwgren, 1994). The initial 1991 rate was very high and treated households and industry similarly; however, due to concerns about competitiveness, the industry rate was reduced to 25% of the household rate in 1993. Some years later, in 1996, it was increased to 50%, and it is now automatically adjusted according to the rate of inflation. The CO₂ tax succeeded an energy tax originally instituted in 1974, and the overall energy tax pressure has in fact hardly increased during the 1990s, although it now targets CO₂ more specifically.

Swedish CO₂ emissions have decreased slightly, from 56.7 million t in 1991 to 55.9 million t in 2000. Emissions have, however, peaked above this level in certain years, in particular after dry summers with little water for hydroelectric power generation.

A first evaluation analysis carried out by the Swedish Energy Agency NUTEK (1994) used the energy-model MARKAL to compute the CO₂ reduction resulting from the tax. It was found that emissions were 3–5% lower in 1994 than they would have been had the energy tax not been changed to a CO₂ tax in 1990.

In a follow-up study by the Swedish EPA (Naturvårdsverket, 1995) the energy modelling was supplemented by extensive interviews, surveys and engineers' calculations. The study related to all sectors except the transport sector, and concluded that emissions had decreased by 19% from 1987 to 1994 relative to baseline. Approximately half of this reduction, 10%, was attributable to the CO₂ tax. The main change was effected in district heating plants with substitution in favour of the use of biomass in heating units. The literature often refers to this reduction; however, if the transport sector is in fact taken into account, the actual reduction in CO₂ emissions from 1987 to 1994 due to the tax amounts to about 3–5%, a decline relative to a business-as-usual scenario, and not in absolute figures.

As a result of the lowering of the industry CO₂ tax in 1993, some research has focused on the effect on emissions stemming from the actual decrease. An analysis from Gothenburg University (Carlsson and Hammar, 1996) shows a 54% increase in industrial CO₂ emissions in Älvsborg County after the lowering of the CO₂ tax, two-thirds of which was explained by the lower tax rate (see Table 4). The method used in this report was a detailed survey of energy consumption among 27 industries responsible for 90% of CO₂ emissions in the specific county. The study revealed a shift from electricity to fuel oil in the wake of the reduced tax rate. The authors show how this finding may be applicable to Sweden as a whole.

Table 4. Effect of lowering CO₂ tax rate on industrial emissions in 1993 (Sweden)

Study	Region	Focus	CO ₂ increase	Increase attributable to lowering CO ₂ tax rate
Carlsson and Hammar (1996)	Älvsborg County, Sweden	27 industries (90% of CO ₂ emissions)	54%	36%

2.3. Finland

At the time of its introduction, the Finnish CO₂ tax had a rather low rate, but on the other hand, there were very few exemptions (Teir, 1999). Only peat, a significant fuel in the vital forest industry, is treated as a CO₂-neutral fuel, despite the renewal period being rather long. The tax has undergone several changes, some due to difficulties with EU law. The most important change is that electricity is now taxed per kWh, and is not differentiated according to CO₂ content.

Finland's CO₂ emissions increased from 62 million t in 1990 to 66 million t in 1997, but then decreased to the original level in 2000. Finland has the highest CO₂ emissions per capita, probably due to the cold climate and various energy-intensive industries.

It is surprising that, despite Finland being the first country to introduce a CO₂ tax, ex-post evaluations have not been carried out, either by the authorities or by independent institutes. The reason may be that the tax was initially low and was seen mainly as a revenue-raising tax. With the recent changes, however, the tax is no longer as modest as it used to be. Much of the analytical work undertaken has focused on the impact on the competitiveness of unilateral taxes.

2.4. Denmark

Denmark's CO₂ tax complements an extensive system of energy taxes; however, before 1993 such taxes were not levied on industry (Larsen, 1999). Since 1996 Denmark has had a fairly complex three-tier system of tax rates for industry, consisting of one standard rate and three reduced rates for energy-intensive processes combined with agreements on energy savings. In comparison with the other three countries, Denmark redistributes the revenue generated by the CO₂ tax on industry to energy efficiency improvements. The CO₂ tax for industry was designed to assure 5% of the 20% CO₂ reduction aimed for by 2005 (base year 1988).

Denmark's CO₂ emissions are subject to considerable controversy. The Danish government insists that emissions must be corrected for electricity exports and imports, but the UNFCCC has not accepted this policy. The baseline year, 1990, was characterized by high electricity imports, straining Denmark's ability to achieve its 21% Kyoto reduction target. In terms of UNFCCC figures, Danish CO₂ emissions were 52.8 million t in 2000, similar to the 1990 level. The Danish government contends that emissions have decreased by about 12%, when corrected for electricity exports. Electricity exports affect emission profiles significantly because of the predominant use of fossil fuels in Danish electricity production (wind power currently accounts for 13% of total production). Electricity exports go mainly to other Nordic countries in dry years, such as in 1996 when CO₂ emissions were 37% above 1990 levels. Since exported electricity was exempt from taxation until recently, the CO₂ emission controversy does not in fact affect an evaluation of the tax scheme.

The Danish system of CO₂ taxation has drawn international interest and some of the first ex-post studies were produced by foreign analysts. Shopley and Brasseur (1996) surveyed the impact of the tax on company management through in-depth interviews with a small sample of companies. Most of the companies had reduced energy consumption by more than 20% without any negative impacts on employment. Clasen (1998) surveyed a small sample of 'best-performance-cases' through company interviews and found similar results, the CO₂ tax, moreover, playing a significant role. Bjørner *et al.* (1998) and Bjørner and Togeby (1999) have compiled a database of disaggregated data for over 5000 companies representing more than 90% of industrial energy consumption. They compare the tax instrument with the agreement instrument and find that companies with agreements (and a reduced tax rate) reduced their energy consumption by 13%, but would only have reduced by 8% had the standard tax rate applied (see Table 5).

The Ministry of Finance (1999) was mandated to evaluate the revised CO₂ tax scheme, however, only ex-post data for 1996 were available. The ex-ante general equilibrium models as used in the development of the tax were again employed and, not surprisingly, it was found that the desired reductions would be achieved. Some key assumptions regarding autonomous energy efficiency and economic growth were, however, changed in the new calculation.

Table 5. Effect of tax versus reduced tax rate with agreement

Studies	Country	Focus	CO ₂ reductions	
			Companies without agreements	Companies with agreements
Bjørner et al. (1998) Bjørner and Tøgeby (1999)	Denmark	5000 companies (90% of industrial energy consumption)	8%	13%

Table 6. Decoupling effects resulting from CO₂ reduction policies

Study	Country	Focus	Period	Production increase	CO ₂ emission reductions
Lindeberg (1996)	Norway	Petroleum sector	–	55%	18% ^a
Enevoldsen (1998, 2000)	Denmark	–	1991–1997	27%	7%

^aLargely due to the tax.

Enevoldsen (1998, 2000) used a comparative approach to assess the effectiveness of the Danish policy on industrial CO₂ emissions. He found that while production had increased by 27% from 1991 to 1997, there had been a decline in CO₂ emissions of 7% (see Table 6). The exact role of the tax could not be quantified, but compared with developments in the Netherlands and Austria, the Danish scheme was seen to be relatively more successful.

The Energy Agency (1999a) has analysed the specific role of the energy conservation agreements (agreements are required in order to become eligible for a reduced tax rate for energy-intensive processes). The evaluation is based on a small sample of in-depth interviews and a larger survey, and relates to the period 1996–1998. Companies with agreements account for 45% of total industrial energy consumption. The interviews provided detailed feedback on the interplay between energy specialists and company managers. The survey showed that CO₂ emissions had been reduced by 1.7% in 1999, and that the total reduction by 2005 could amount to as much as 6.3% (see Table 7). About one-third of these reductions were already profitable, but the new regulatory regime helped focus attention on energy efficiency.

Table 7. Effect of agreements required for reduced CO₂ tax rate (energy-intensive processes)

Study	Country	Period/ focus	CO ₂ reductions	Potential CO ₂ reductions by 2005
Energy Agency (1999a)	Denmark	1996–1998 small in-depth interview plus larger survey	1.7% (1999)	6.3%

The completed ex-post studies of the CO₂ taxes do not present unambiguous results, because focus and methodology differs. Most studies are partial in their focus and relate to one or more sectors of the economy. Some studies have been carried out just a few years after the introduction of the taxes and, as such, do not present a comprehensive assessment of the effects of the taxes. To the extent that it is possible to summarize the present knowledge about the effects of the CO₂ taxes, there seem to be indications for relatively marked effects in Denmark as compared with the other Nordic countries, since Denmark is

the only country whose CO₂ emissions have been reduced, although only if corrected for the excluded electricity trade. With regard to Norway and Sweden, effects of the CO₂ taxes can be identified in particular sectors in relation to business-as-usual scenarios. Finland's CO₂ tax has not been comprehensively evaluated ex-post, but has reached a tax level which gives expectations for measurable effects. The explanation for the marked effects in Danish industry appears to relate both to the fuel switch away from coal, as well as to redistribution of tax revenues towards energy efficiency investments.

3. Methods for ex-post evaluations

From the above review, it can be seen that rather different methods have been used for ex-post evaluations, ranging from casual interview techniques to rather complex economic models. What are the advantages and disadvantages of the different methods, and which presents the most promising avenue for future evaluations?

The following principal methods and their combinations have been identified:

- case studies of company responses based on interviews and some hard data (Shopley and Brasseur, 1996; Clasen, 1998)
- detailed technological assessments of changes in energy technology and marginal abatement costs for particular sectors (ECON, 1994, 1997)
- surveys covering a larger sample of companies using a standard questionnaire (Energy Agency, 1999a,b)
- comparative studies using simple time-series analysis (Enevoldsen, 1998, 2000)
- panel databases with statistical analysis (Bjørner *et al.*, 1998; Bjørner and Togeby, 1999)
- bottom-up energy systems modelling (NUTEK, 1994, 1997)
- calibration of general equilibrium models and macroeconomic modelling with historical data (Larsen and Nesbakken, 1997)
- combinations of models and surveys (Ministry of Finance, 1999), or combinations of in-depth interviews, technological assessments and surveys (Naturvårdsverket, 1995).

Before considering these methods in greater detail, a definition of an ex-post evaluation may be useful. The concept 'evaluation' may intuitively be understood to refer to all types of assessments of public policy, but according to Vedung (1997: 18) this perception is flawed. Evaluation refers to a *subsequent* assessment. Subsequency does not imply that a policy is terminated at the time of evaluation, only that it has been agreed and has been under implementation for some time. We use the term 'ex-post' to emphasize the subsequency of evaluations, as opposed to the ex-ante assessments of policies that are carried out before a policy is agreed. However, one can also simply use the concept 'assessment' in reference to ex-ante, and the term 'evaluation' in reference to ex-post.

3.1. Modelling problems

Conventional economic models, whether input–output, macroeconomic or general equilibrium, which can be useful for ex-ante assessments, are less suitable for ex-post evaluations. The basic reason is that these models are designed for forecasting and building on simplified key assumptions. One crucial simplification is the concept of economic rational agents.¹ In practice, one of the main accomplishments of economic instruments such as CO₂ taxes is to direct attention to an area, previously peripheral for

many actors, where an attempt to achieve an efficient use of resources has been neglected. If in evaluating these instruments it is assumed that actors are rational, not only after the introduction of the tax, but also before, the positive results of the tax may be underestimated.

To this axiomatic discussion can be added some more specific comments that relate to the conventional shortcomings of modelling. One of the main expectations related to economic instruments is dynamic efficiency; for instance, incentives to develop new technology in response to cost increases (the Porter hypothesis: see Porter and van der Linde, 1995). Many economic models are nevertheless incapable of handling technological development. Only the more advanced models operate with autonomous efficiency improvements, unrelated, however, to the rate of the tax under scrutiny.

Further issues require careful consideration in relation to specific models: for instance, the number of sectors represented in the model, freedom to select different energy supply solutions, and possible alternations between capital and energy, among others. Barker (1996) has warned that economic models have often been developed for specific purposes, different from economic instrument analysis purposes, and that they are thus insensitive to the parameters crucial for modelling the impact of carbon-energy taxation. The outcome of any model must be treated as a conditional analysis, not as a specific forecast (Jespersen *et al.*, 1999).

Statistics Norway has used economic models for ex-post analysis by applying a counterfactual approach. First, established models are calibrated in accordance with the historical data (economic and environmental), so that they fit the actual trajectory. The model is then run without the tax in order to establish a baseline for the development as it would have been without the CO₂ tax. Although this approach makes it possible to produce a specific figure for the impact of the tax, the models contain several lock-ins that deserve to be reflected upon. The use of a Leontieff production function in the input–output analysis means that the tax is added to the price, making it impossible to discern factor substitution. It would require a more dynamic input–output analysis to allow for factor substitution.

Bottom-up energy systems modelling represents an alternative approach in which the starting point is the energy system itself. Being fairly disaggregated, these models tend to work from specified energy markets and up towards the consequences for the energy sector as a whole. They are not connected with prices or taxes, but work from specifications of various technologies. Broadly speaking, they are unable to include feedback from the economic system. This represents an engineering approach which has been criticized for employing overly optimistic assumptions about the implementation of known technologies regardless of cost. It seems to be fairly well developed in the work of Danish and Swedish energy institutes and is represented in NUTEK's MARKAL model.

This is not to imply that other methods are without drawbacks. Below, some alternative methodological approaches available in the tool-box, together with their associated properties, will be more carefully considered.

3.2. Case studies

The case study method is often incorrectly seen as a purely sociological–anthropological approach that provides no basis for generalization. As emphasized by Yin (1984), while the case study method precludes statistical generalization, it does in fact allow for analytical generalization.

If case studies are carefully chosen and designed in accordance with explicit hypotheses about causal relations, they may provide valuable information which can be further tested using more rigorous quantitative methods. Case studies can, therefore, be useful when preparing for surveys or statistical analyses, and individually they may also provide valuable in-depth information about the operation of a

tax scheme. The interplay between tax inspectors, energy specialists and industries, for instance, is probably best understood by means of a case study interview method.

Case studies can also be supported by quantitative data. However, since statistical generalization is not possible, the case study method does not permit us to quantify the exact impact of a CO₂ tax.

There are profound problems associated with conducting interviews. The interviewee may find it ethically less defensible to admit the role of taxes and may perhaps emphasize the role of other more altruistic concerns (such as green management or concern for the environment), making it difficult to avoid a bias. Additionally, if target groups find the use of the tax instrument unjustifiable, they may be less likely to admit its significance.

3.3. Assessment of technological options and marginal costs

Studies in which specific technological options are evaluated and specified require specialized knowledge about the specificities of particular sectors or industries, but may, as in the case of the Norwegian petroleum sector, provide indispensable information on strategic decisions in key sectors.

If the marginal costs of various technological options can be identified, the analysis may point to the role played by the tax. The marginal cost approach, nevertheless, assumes that actors are rational utility-maximizing entities. While this may be a convenient and useful assumption in theoretical economic analysis, ample empirical and theoretical evidence exists to suggest apparent cognitive constraints on rational behaviour. As pointed out by North (1993), rational decision-making is most likely to occur in circumstances with simple causal relations and where decision-making is repetitive.

Close-to-optimal use of energy would only be expected in very energy-intensive companies or among actors specialized in providing energy supplies (e.g. district heating units), whereas there may be ‘low-hanging £10-notes’ in energy management in advance of the introduction of a CO₂ tax among many of the other actors.

3.4. Surveys

Surveys, either via telephone, letters or personal interviews, represent a systematized approach to interviewing in which data are collected in accordance with a harmonized approach that may allow for subsequent statistical analysis. It is a standard technique in political science, in particular for electoral research.

Through the use of surveys, target groups can be asked to identify and rank the significance of various motives for their behaviour. We can then examine the interplay of different policy instruments by asking respondents to rank their importance for the decisions they have taken on energy management, etc. While the survey technique can be fairly advanced, a major problem in the present context is that respondents cannot be expected to be able to deliver as accurate information on energy consumption as they can on voting behaviour. The respondent is normally unlikely to have those figures to hand that would be useful for the analysis.

One possible solution would be to combine survey data with disaggregated panel data on consumption of energy, production output, and so on (cf. panel database below). In general, we would not expect surveys to be able to provide more than broad-brush responses on the role of a tax in relation to other variables, and it would not permit a quantification of the role of the tax. Some of the bias applying to in-depth interviews can also occur in surveys.

3.5. Comparative studies

The comparative approach is less demanding in terms of primary data collection than many other methods, and it offers opportunities for controlling independent variables. The comparative method need not be a comparison of different countries and associated emissions profiles, the comparison can also be narrowed down to cover regions or sectors within a country.

The comparative method takes its point of departure in simple time-series, and analysis is conducted by controlling different independent variables. It is a standard technique within political science research, in some cases supported by more advanced statistical tools such as regression analysis.

Comparative analysis, like case study methodology, requires fairly explicit hypotheses on the expected outcome of particular cases, as would be expected from the causal links claimed by the relevant theory.

3.6. Panel databases with statistical analysis

The construction of a panel database with disaggregated annual data on the relevant target groups allows for fairly advanced statistical analysis, for example regression analysis. The panel database approach shares some features with conventional economic modelling; one of the crucial distinctions, however, being the use of micro data.

For industry, the relevant data would include parameters such as energy consumption, related CO₂ emissions, turnover, value added, profits and employment. For households the relevant data would comprise income and consumption data.

In order to investigate the impact of the tax, energy prices and specific tax levels would have to be included in the database. Competing policy instruments, for instance subsidies and voluntary agreements, could be included as well. Changes in emission profiles that follow from changes in tax rate(s) could then be analysed. One advantage of the approach is that local variations in electricity prices will be covered in the micro data.

The method has been employed in the work of Bjørner *et al.* (1998) and Bjørner and Tøgeby (1999) for the Danish CO₂-tax. Data have been established through Statistics Denmark's energy surveys and complementary data from other surveys. The method is very demanding in terms of data and manpower.

4. Concluding remarks

The choice of methodology for ex-post analysis is obviously constrained by the resources available. The availability of resources may be a function of the significance of the issue under scrutiny, so that more demanding approaches for ex-post analysis will be chosen for vital types of emissions such as CO₂. More simple methods can be useful for 'minor' environmental taxes and charges.

One of the advantages of conventional economic modelling is that one can construct a baseline, i.e. a scenario for business-as-usual. Once a baseline is established, it is possible to obtain rather specific estimates for the role of the tax; however, the conditionality of the modelling exercise is sometimes neglected.

One of the drawbacks to some of the alternative approaches considered here is clearly the difficulty in identifying a suitable baseline, i.e. the development had no tax been introduced. There seems to be a distinction between ex-post methodologies that (1) need a baseline because actual developments have to

be compared with projected developments for assessing the tax effect (revealed behaviour), and (2) methods that aim to estimate the impact itself (stated behaviour).

The technology-marginal cost approach (see ECON, 1994, 1997) obviously allows us to distinguish between measures that were profitable only with the tax, and hence to deduct the emissions under business-as-usual conditions, as done by Lindeberg (1996). The problem is that the approach is slightly static, as the feedbacks generated by using the same resources for conventional investments rather than emissions control cannot be included. The comparative approach used with the panel database also permits us to construct the role of the tax in relation to other variables.

Under the comparative approach the use of a ‘most similar cases design’ (see Lijphart, 1975) will allow us to compare the effects of a tax regime in one country with a business-as-usual approach in another. Assuming that industries in the two countries have access to the same production technologies, and selecting the cases in such a way that the essential economic framework variables are kept constant, we may reveal the impact of the tax. A more careful disaggregation of national data into different sectors, however, may be a necessary component in this analysis.

Under the panel data analysis, regression analysis will provide a single coefficient, the regression coefficient, for the ability of shifts in energy taxes to explain shifts in energy consumption. The closer this coefficient is to a value of 1, the more explanatory the tax (given reliability tests are passed). One particular advantage is that the problem of highly aggregated data in some modelling approaches can be avoided, thus providing a more accurate assessment of the tax. Panel data analysis may therefore also prove to be a promising approach for the evaluation of CO₂ and other environmental taxes.

The existing evaluation studies of the Nordic CO₂ taxes seem not only somewhat dated but also rather partial in their scope. For the purposes of more rigorous evaluations of the role of CO₂ taxes we need more comprehensive assessments. The insights to be achieved from more rigorous studies could also help improve ex-ante modelling of carbon taxes.

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Notes

- 1 While input–output analysis does not incorporate this central element of neoclassical theory, i.e. utility-optimization by economic agents, CGE models do.

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