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Determining the Environmental Effects of Indirect Subsidies

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Determining the Environmental Effects of Indirect Subsidies: a Methodological Approach with an Application to the Netherlands

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Abstract

Up to now a clear theoretical and methodological framework for economic-environmental analysis of environmentally damaging subsidies is lacking. Environmentally damaging subsidies are all kinds of direct and indirect subsidies aimed at achieving a certain (often non-environmental) goal that produce negative external effects to the natural environment. This article develops a transparent method to determine the environmental impact of indirect government subsidies and derive policy lessons. This method has been applied to several major subsidies in the Netherlands, namely in agriculture, energy, and transport. The results reveal large environmental effects, which need to be taken seriously by policy makers. The method enables policy makers to evaluate the environmental impacts of indirect government subsidies.

Acknowledgement

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1. Introduction

At the World Summit on Sustainable Development in Johannesburg government leaders have re-confirmed that sustainable development should be a top priority for government policy. However, research suggests that many current government policies and public structures are still subsidising an unsustainable development. Governments spend hundreds of billions of dollars to subsidise production and consumption in resource-intensive sectors like agriculture, transport, energy, water, forestry and fisheries (van Beers and de Moor, 2001; OECD, 1998 and 1999). Many of these subsidies especially indirect types of support, cause unintended but significant environmental effects.

As opposed to direct subsidies, which are visible at the expenditure side of the government's budget, indirect subsidies often are not recognised as subsidies. They include various types of governmental interventions, such as tax exemptions for particular groups, determination of minimum prices for agricultural products, and financial guarantees, such as export credit facilities. It is moreover quite difficult to determine the environmental consequences of indirect subsidies, both in theory and in practice. There is hardly any scientific literature on the analysis of public subsidies, neither in public economics nor in environmental economics. Standard theory in public economics analyses subsidies often as negative taxes without any specific features assigned to subsidies (Atkinson and Stiglitz, 1980). Empirical studies of the effects of subsidies assume certain relationships between on the one hand changes in relative costs and revenues and on the other hand choices regarding production and consumption by the subsidy recipient. These linkages, however, are hidden in implicit assumptions and mechanisms in empirical models.

This paper reports a policy framework founded in microeconomic theory to determine the environmental effects of government subsidies in a transparent and relatively straightforward manner. This is based on van Beers et al. (2002). The approach includes a set of transparent models for different circumstances and subsidy types. In addition, it covers the assessment of a number of environmental effects as well as aggregation and weighting of these into an aggregate environmental index.

The definition of a subsidy is obviously an important starting point for our analysis. We have used a broad definition, namely all government interventions that directly or indirectly keep prices for consumers below, or for producers above, market level prices.[1] A useful taxonomy of subsidies is as follows:

- Tax subsidies through deductions, exemptions or special tariffs such as reduced energy taxes for specific sectors or the low VAT rate on meat.
- Public provision of goods and services below the cost such as infrastructure or associated services.
- Capital subsidies such as loan guarantees, debt forgiveness or government loans with lower than market interest rates or under soft conditions.
- Price regulation: policy measures through the market mechanism that shift the cost burden (partly) to market players; examples are minimum prices for agricultural products and maximum prices through price controls.
- Quantity restrictions: regulations towards a minimum use of a certain input or product; an example is the regulatory rule set by Germany that electricity companies should use a minimum quantity of domestically produced coal.
- Trade barriers: regulation of imports through rules, quotas and export credits.

[1] Although the lack of government policy aimed at internalising external effects is not considered a subsidy here, the policy framework is also suitable to analyse and calculate the environmental impact associated with external effects.

The organisation of the paper is as follows. In the next section the structure of the policy framework is outlined. Section 3 then describes the concrete microeconomic models used to translate the policy framework into an operational tool. Section 4 applies the method to, and reports empirical results for, three major indirect subsidies in the Netherlands. These relate to the production sectors agriculture, energy and transport. A final section presents conclusions.

2. The policy framework

2.1 Policy framework

The policy framework is illustrated by the stepwise procedure depicted in Figure 1.

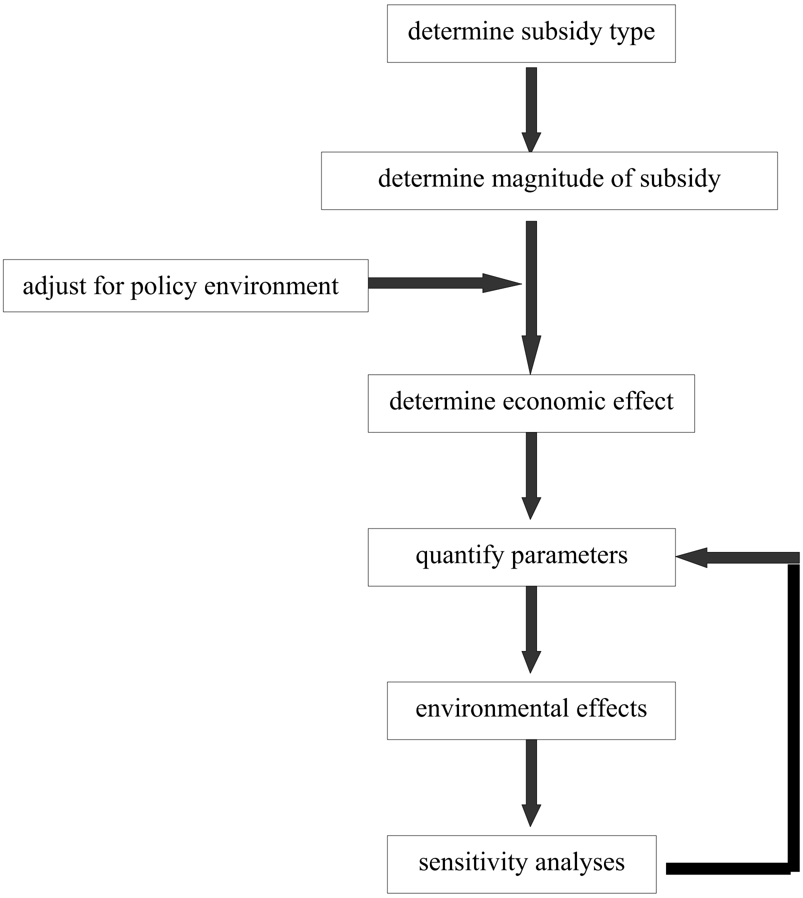

Figure 1: Policy framework for subsidy assessment

First the type of subsidy is determined to identify the specific model needed for the analysis. This is followed by an assessment of the (monetary) magnitude of the subsidy, which can be regarded as a rough measure of the magnitude of the economic and environmental disturbance caused by the subsidy under consideration. The next steps are formalisation and quantification of the mechanisms that determine the economic effects of the different indirect subsidies. The mechanisms differ between subsidy types and can include a number of economic variables, including supply, demand, prices, input mix and technology type. In a subsequent step, the economic effects are the inputs to the calculation of environmental impacts. The end result is a quantitative relationship between the magnitude of the subsidy on the one hand, and the generated economic and environmental effects on the other. Note that policy filters may be required to correct for the impacts of other government policies if these enhance or compensate the effects of a particular subsidy. One example from our study is the combination of quotas and the subsidy type 'guaranteed prices' for milk in the agricultural sector.

The magnitude of a subsidy is determined as the amount of money (prices or cost savings) or as a volume of a physical product (functional units or kg). If it is not possible to quantify the subsidy, this does not necessarily mean that the analysis of the impacts of such a subsidy will only provide qualitative information. An example is a production subsidy that stimulates use of another production technique. A comparison of the environmental effects of the different techniques is then still possible.
From a theoretical perspective, a key factor behind the impact of a subsidy on the economy is the point of incidence of the subsidy in the chain of activities and markets. This is illustrated in Figure 2. A chain with three activities offers a sufficiently rich framework to analyse both the flows of intermediate goods and linkages between economic activities (e.g., activity 1 $\rightarrow$ 2), and the final products going to consumers (e.g., activity 2 $\rightarrow$ 3).

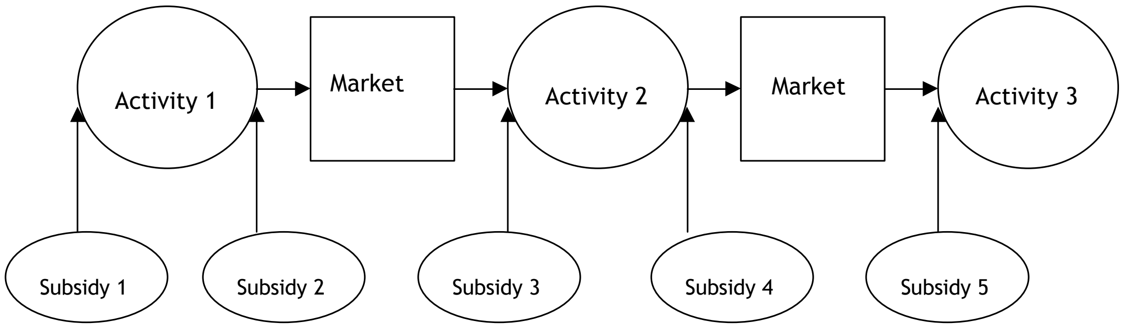

Figure 2. Points of incidence of a subsidy in activities and markets.

The activities are connected through markets, which transmit the impact of the subsidy to other economic variables. For example, producer subsidies can affect input- and output prices directly and the quantities indirectly. The reaction of the prices and, hence, the effect on the quantities produced are incorporated in the price elasticity. The ultimate effect of a subsidy depends partly on the kind of competition in the relevant markets. An example is gasoline tax reduction to truck drivers. The fierce competition in this sector promotes the transmission of the resulting price reduction to other sectors in the production chain. As a result, the economic activity of the transport sector hardly changes. Consumer subsidies like VAT-exemptions affect the quantities demanded through the price directly. Both an income and price effect then emerge. A tax exemption for commuting traffic, for example, increases income and reduces the costs of commuter traffic. All these examples require specific models for their analysis.

2.2 Indirect subsidies for producers

On the supply side, the first effect of a subsidy is reflected in the behaviour of the decision-makers in companies or within a sector. The main question is what the consequences are for inputs, technology and output (scale of production or volume). Technology is seen as being related to the production process within a company, particularly the process technology. The inputs that have an effect on the environment are energy and raw material resources, including land and water (especially in agriculture). A subsidy that affects the cost of using raw and auxiliary materials can stimulate the use of one technique over another. Capital subsidies and R&D subsidies usually allow more freedom in terms of choice of techniques, but even they can impose a particular technique – explicitly or implicitly – which may have consequences for the environmental pressure per unit of output.

At a company level it is possible to determine whether a specific subsidy affects the prices of inputs or outputs, costs or profit. Some subsidies have a direct effect on the prices of inputs or output, whilst others have an indirect effect on prices, for example, through costs or volume restrictions. A subsidy on an input will have a relatively small effect on the output if the non-subsidised inputs are essential or irreplaceable (i.e. there are no substitutes) and the price elasticity of demand for the end product is low, or if the input makes up only a small part of the overall marginal costs. Such a subsidy primarily affects profit. Where there is a substitute there will be a shift in the input mix from a non-subsidised to the subsidised inputs. Depending on the price elasticity in the demand for the end product and the magnitude of the subsidy in terms of its effect on the marginal costs, there can be a significant output effect.[2] If a subsidy on an input stimulates or imposes the use of a particular input and the effect on the prices of the end products of the company concerned is small, then the analysis should focus on the relevant factor market.

In addition to the substitution possibilities between and within input factors, the economic effect also depends on the type of output and input markets. For example, where there is fierce competition on the sales market, a capital subsidy via a soft loan or low required return on investments might lead to lower output prices, a demand for greater volume and consequently to increased production. It will be very difficult to trace or quantify the effect of capital subsidies because it runs through the 'black box' of investment decisions – where uncertainties, coincidence, subjectivity and dynamic aspects dominate.

A capital subsidy, or a subsidy on a particular type of capital good, is a subsidy on a company's fixed costs. These subsidies permeate slowly through the sector under consideration. Capital subsidies allow much room for manoeuvre as regards the choice of production process, and are therefore not as harmful to the environment. Conversely, if these subsidies are abolished the 'environmental benefits' are not felt until much later. In most cases where these subsidies harm the environment it is because they lead to new development work or are given to polluting industries that have a long technical life.

In contrast, subsidies on variable costs result in immediate consequences for production decisions. Such subsidies (e.g. on energy, equipment or water) immediately discourage the innovation that would lead to more economic consumption. This has far-reaching environmental consequences because it is precisely the extraction of raw materials and energy and the manufacture of equipment that are among the most polluting economic activities. Given that the use of certain raw and auxiliary materials often also means that only one or a small number of techniques can be used, subsidies on equipment, energy and water easily lead to 'lock-in effects'. These can be reinforced by subsidies on certain types of capital goods. In addition, there is a category of subsidies on fixed costs that have a major environmental impact. These are subsidies without which an entire economic activity would not start or take place at all. A capital subsidy on new development work in the mining industry is a clear example of this.

In principle, it is possible to consider that almost all indirect subsidy effects take the form of price changes. In this regard the notion of a shadow price is relevant. A 'shadow price' is the change in costs of production that results from moving, for a given level of production, from a certain input to one that is stimulated by an indirect subsidy. In the case of a subsidy through volume regulation on a (domestic) input, a producer is forced to use more of this domestically produced input than is

[2] Sometimes this might even happen within a subset of production factors – take the energy input mix, for example. Such a substitution effect can have major environmental consequences, even if the sale of the end product is hardly affected by the subsidy.

economically efficient. This will make the production costs higher than without the subsidy; the difference per unit of output is the 'shadow price'. Also a tax exemption on an energy-intensive input, for example, is the shadow price of that input. However, in the case of a tax exemption that has a general effect on profit it is less clear how the economic effect is reflected in the price, especially when a company produces several products. In this case the effect depends on competitive relationships on the input and output markets. For example, if the output market is very competitive, the producer will be quick to reflect the tax exemption in the prices of the end products.

A subsidy on the output price immediately affects the proceeds from the product, which has a significant impact on both the volume demanded and the volume supplied and thus also on the volume of inputs required.

Guaranteeing a minimum price, e.g. for primary agricultural products in the EU, gives the producer a direct and strong (price) incentive to increase production in order to obtain a maximum profit from the subsidy. Minimum prices have far-reaching economic consequences and invite a chain of subsidies. One direct consequence is that excess (supply) is created, and that new subsidies are required to transport and store this excess, which is then eliminated by selling it to domestic consumers or on export markets with yet more subsidies. Furthermore, a system of minimum prices can only be maintained if import barriers are raised to keep out cheaper products from foreign competition. Ultimately such output price subsidies can even lead to a change in the production structure and a 'lock-in' of subsidised activities (see below). A minimum price subsidy is often part of a more complex policy package, e.g. with volume regulation to avoid excess supply.

2.3 Indirect subsidies for consumers

We now turn to subsidies for consumers, i.e. the demand side. In general, price effects on consumption can be assessed by examining market prices, incomes and substitution effects.

In accordance with market forces, a subsidy in the form of a maximum price has an immediate effect on demand. The output price is lower and consumers will therefore increase demand. Subsidies via indirect taxes, such as no-VAT-on-airline-tickets or exemption from excise duty on kerosene, are also directly reflected in the end prices and therefore have a direct effect on the volume demanded.

Subsidies running through income taxes affect both income and the shadow price and therefore have a strong effect on demand. Tax exemption for a particular activity, such as the former flat rate allowance for commuting between home and work, leads not only to a higher net income but also to a reduction in the costs of the activity in question. As a result, there is a larger volume of commuter traffic. In the specific case of the flat rate allowance for travel costs, the subsidy may stimulate people (continuing) to live further away from work, which is a form of 'lock-in' of activities with undesirable environmental effects.

Subsidies via income taxes have another indirect effect, namely on the distribution of income. Taxes are partly intended to affect the distribution of income, but subsidy measures can undo these envisaged effects and contribute to inequality of income. Subsidy measures in progressive tax systems in particular can have this effect. An analysis of this effect is, however, beyond the scope of this study.

2.4 The scope of effects of indirect subsidies

It is useful to look at the extent to which subsidies have partial or limited versus significant consequences. For example, the interim or ultimate demand for a product may be significantly affected as regards magnitude or composition, or the sector structure may change (the 'technology' above company level). In such cases a partial analysis might not offer enough insight.

Some economic effects take time since a lot of changes come about through investments. A dynamic breakdown is necessary before aspects such as tax deduction for investment in capital, write-offs and interest payments can be adequately analysed (Atkinson and Stiglitz, 1980). Gradual discarding of obsolete technology, write-offs, future expectations, accumulation of capital, and long-term environmental effects then give the analysis a dynamic character.

If anything, the effect of a subsidy that leads to a 'lock-in' of activities is even more complex. The term 'lock-in' indicates that an unwanted or less than optimum technology or method of production dominates as a result of a historical process of positive feedback or self-reinforcement ('path dependence') based on coincidences ('historical accidents'). The source of the positive feedback is the existence of increasing returns to scale, caused by processes on the demand or supply sides of the economy.[3] Subsidies can influence these returns to scale and thus tip the balance in historical development to a 'lock-in' of an unwanted method of production. For example, the price subsidies in agriculture have led to a gradual shift in the production structure. Specific capital subsidies that are accompanied by technological requirements have a stronger lock-in effect than generic capital subsidies, which reduce loan costs for example but leave companies free to use the resulting extra financial scope as they see fit. Significant lock-in effects also result from sunk costs. For example, if the government decides to build a (subsidised) coal-fired power station, this will be around for the next 40 or more years. As a result of the accompanying sunk costs it will remain cheaper throughout that period to continue to use the station than to transfer to an alternative that is cheaper or less environmentally damaging.

Furthermore, a lock-in makes it very difficult to change the existing situation; modifications require not only 'correct prices' but also additional policy. Although the lock-in effect is the most important long-term consequence of subsidies, it is very difficult to quantify. This is because one would have to replay the complex historical changes in technology and sector structure without the presence of subsidies. A model able to do this would involve too many unverifiable assumptions. It might perhaps be possible to gain some insight in specific cases from a comparison between countries with different systems and development patterns.

However, this presumes an extensive *ceteris paribus* clause. A good point of departure may well be that quantifying the environmental effects of subsidies without lock-in effects will generally lead to a lower bound on the actual environmental effects, since the impact of the lock-in will be to strengthen the change caused by the subsidy. The specific environmental effects of the subsidy will in this case be greater with than without the lock-in, since the result is an increase in the volume of the product to which the environmental effects are related.

2.5 Environmental effects

In order to arrive at an estimate of the environmental effects of subsidies it is first necessary to consider the relationship between the economic effects as discussed above on the one hand and the relevant environmental effects on the other. The environmental effects can be related to the inputs or outputs. Where possible, we will assume a fixed relationship between outputs and environmental effects. The environmental effects will be aggregated to form theme indicators.[4] The environmental effects that are relevant for this study are as follows:

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[3] Examples are network externalities (telecommunication), imitation (fashion), information externalities (more users generate more awareness), mass production (lower production costs) and technological complementarities such as infrastructure and sub-technologies (e.g. petrol-driven cars, refineries, filling stations). See also David (1985) and Dosi et al (1988).

[4] These indicators are based on the Environmental Performance Indicators (EPI) method. See VNCI (2001).

- Enhanced greenhouse effect: we will focus in particular on carbon dioxide (CO_2), as this is relevant for both energy and transport. For the agricultural sector methane (CH_4) and nitrous oxide (N_2O) emissions are also relevant.
- Acidification: NO_x and SO_2 emissions are particularly relevant for the energy and transport sectors; NH_3 emissions are particularly relevant for agriculture.
- Photochemical creation of ozone: emissions of volatile organic compounds (VOC) and carbon monoxide (CO) occur in particular in transport. NO_x emissions are also important.
- Eutrophication: phosphates, nitrates, biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The phosphates and nitrates in particular are relevant in the agricultural sector.
- Land use: although land use is not an environmental impact indicator, its impact is important in the agricultural sector. It also plays a role in discussions about possible indicators for biodiversity.

In choosing the above effects for this study we are focusing on the most important environmental problems as indicated in the National Environmental Policy Plan 4 of the Dutch government. The decision to limit this study to the effects on the most important environmental themes is motivated mainly for practical considerations; more indicators can easily be added in a subsequent study, such as depletion of the ozone layer, human and ecological toxicity, soil, water and groundwater pollution, noise pollution, odour nuisance, safety, waste, and groundwater pumping (see VNCI, 2001).

The analysis of the environmental effects translates the economic effects – on inputs or outputs – into environmental effects. This is done using various data sources and parameters, including those that were available at the National Institute for Public Health and the Environment (RIVM).

Next, Environmental Performance Indicators (EPIs) of each emission are created by multiplying each type of emission (in kg/year) in a particular category – e.g. CO_2 in the case of global warming potential – with a (unique) weighting factor. The results for all kinds of emissions within each category are added together, which produces the EPI for that category. This gives the following equation for calculating the environmental impact *j* if this is based on *n(j)* separate emission types:

$$EPI\ (j) = \sum_{i=1,\ldots,n(j)} (emission\ type\ \ j, i) \times (weighting\ \ factor\ \ j, i)$$

Note that it is possible, in principle, for the emission of a particular substance to contribute to several EPIs to which different weighting factors apply. Appendix II contains an overview of the weighting factors used. Finally, a sensitivity analysis will have to be performed in which another interpretation of the parameters will give insight into the reliability of the calculated effects.

3. Detailed description of the method

In describing the specific models used to assess the economic and environmental impacts of specific subsidies, we will take as a starting point the typology of subsidies as presented in the introduction (see also Table 1). This section summarises a set of formal models, presented in non-technical terms, to assess the economic and environmental effects of different types of subsidies. This consists of two elements. First, a list of factors that together determine the environmental effect(s) of a particular subsidy is presented. This suggests which data are required to apply a specific method. Second, a formal relationship between the factors (variables) is presented. This indicates how the data have to be combined so as to derive the environmental effect(s). It is important to note that the availability of data is the main restriction on the decision whether to include more or less factors, and as an implication, to use a more or less complicated model structure. Table 1 provides an overview of the determining factors per subsidy type, where in two cases a distinction is made between having all relevant data available or not.

Table 1. Factors that determine economic and environmental effects, per subsidy type and according to availability of data

Type of subsidy	Relevant data available	Certain data unavailable
1. Subsidy in the form of reduced input prices	• Magnitude of subsidy • Parameters of production function • Magnitude of relevant input • Output price and input prices • Pollution intensity of production	
2. Subsidy on inputs in the form of tax measures (tax subsidies)	• Magnitude of subsidy • Price reaction in demand • Output price reaction in supply • Input price reaction in supply • Pollution intensity of production	
3. Subsidy on outputs in the form of tax measures (tax subsidies)	*3.a. Production* • Magnitude of subsidy • Price reaction in demand • Price reaction in supply • Pollution intensity of production *3.b. Consumption* • Magnitude of subsidy • Demand effect of the subsidy • Pollution intensity of consumption or production of consumed product	*3.a. Production* • Magnitude of subsidy • Price reaction in equilibrium • Volume • Pollution intensity of production
4. Public supply below cost price	Like case 1	
5. Capital subsidies	Formal analysis problematic	
6. Minimum prices	• Currently supplied volume • Demanded volume at free market price • Pollution intensity of production	• Currently supplied volume • Demanded volume at world market price • Pollution intensity of production
7. Volume regulation	Like case 6	
8a. Import barriers (trade measures)	Like case 7	
8b. Export credit guarantees (trade measures)	Formal analysis problematic	

A number of aspects summarised in the Table are presented in somewhat more detail below, and much more extensively in Appendix I. Note that all approaches are based on information about marginal costs. This is consistent with the fact that all the subsidy types in the table affect the marginal costs of production or the marginal utility of consumption of a particular product. If this would not be the case, there would be no behavioural effect of a subsidy, and therefore no economic and environmental impacts.

1. Subsidy in the form of lower input prices – technology effect is dominant

If detailed information about production functions is available, such as with regard to energy and agriculture, the environmental effects of subsidies that are applied to the prices of input factors are determined by five variables:

- The magnitude of the subsidy
- The parameters of the production function
- The magnitude of the relevant input
- The output price and input prices
- The effect of the relevant inputs and output on environmental indicators.

The equations that play a role here are (2), (3) and (16) to (23) in Appendix I. Sub-methods 2 or 3 should be used if effects on factor or product markets are relevant.

2. A subsidy on inputs in the form of tax measures – dominant effect of factor market

In the case of a tax exemption on an input factor in a production process the increased environmental impact depends on five variables:

- The magnitude of the subsidy
- The price reaction of demand[5]
- The output price reaction of supply
- The input price reaction of supply
- The pollution intensity of production.

Equation (41) in Appendix 1 indicates the relationship between these variables.

3. A subsidy on output in the form of tax measures – effect of product market is dominant

3.a. Production

A tax exemption on the price of an output has an effect on the environmental impact of production through the interaction of four variables:

- The magnitude of the subsidy
- The price reaction of demand
- The price reaction of supply
- The pollution intensity of production.

Equation (34) indicates the relationship between these variables. If separate information is not available about supply and demand, the effect of the subsidy will depend on the following variables (see equation 35):

- The magnitude of the subsidy
- The price elasticity of the equilibrium volume
- The equilibrium volume and price
- The pollution intensity of production.

3.b. The effect of subsidies on consumer decisions

The extent to which a subsidy affects the environmental impact depends on the following variables (see equation (53) in Appendix I):

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[5] The following is meant by 'price reaction of demand (supply)': the absolute change in the demanded (supplied) volume that occurs in reaction to a given price change. The following is meant by 'price elasticity of the equilibrium volume': the relative change in the demanded volume (with respect to the equilibrium state) as a result of a relative price change of 1%.

- The magnitude of the subsidy
- The effect of the subsidy on demand. This effect depends on the assumed functional specification of the utility function. It is also possible for a subsidy to produce cross-effects, in which case the effects must be added together. However, this will not be that relevant in practice since the cross-effects are relatively small compared with the 'own' effects;
- The pollution intensity of consumption or production of the consumed product to which the subsidy applies.

4. Public supply below cost price
This amounts to determining the effect of a reduction in the input price and involves using the approach described under point 1 or 2.

5. Capital subsidies
It is very difficult to quantify the economic effects, and consequently the environmental effects, of capital subsidies. This is because these subsidies change the conditions under which companies take decisions about investments. The specific expertise and information on such effects may well be available in the field of corporate financing, but a more detailed analysis is outside the scope of this study. Only in specific cases is it possible to carry out an analysis using a different approach. For example, in the case of low return on the government share in an airport the indirect subsidy is in the form of low airport taxes, which allows carrying out an analysis using approach 2 (a tax exemption on an input).

6. Minimum prices
The extent to which minimum prices affect the environmental impact depends on the following variables (see equation (54) in Appendix I):

- Supply at a guaranteed price, or supply in the current situation.
- Supply at the free market price. This requires a hypothetical situation, which, in some cases, can be based on the application of simple rules such as price change multiplied by elasticity, or on earlier studies (e.g. with CGE models). Note that if the world market price is not equal to the domestic free market price, then the supply at the world market price is relevant. It is very difficult to determine the free market price if there is no world market price or when a hypothetical national free market price applies.
- The pollution intensity of production.

7. Volume regulation
Since volume regulation and minimum prices usually go together, the method as described under point 6 can be used here.

8. Trade measures
8a. Import barriers
The same applies here as under 7 since import barriers are a special type of volume regulation.

8b. Export credit guarantees
Export credit guarantees are a type of subsidy the effects of which are very difficult to quantify. As under 5, it is a question of the effect on behaviour in an uncertain situation. It is difficult to determine result in terms of polluting emissions.

Finally, if the specific environmental effects of a subsidy are determined for a certain subsidy case, then the final step is to aggregate and weight these according to the approach presented in Section 2.5.

4. Empirical application and results of the methods in the policy framework

The method of the previous section has been applied to a variety of indirect subsidies within the sectors agriculture, energy production, and transport (van Beers et al., 2002). In making a selection of cases, a balanced distribution was aimed for in terms of subsidy types, subsidy size, the expected impact on producing and consuming activities, and the expected environmental impact of the additional activity induced by the subsidy. We illustrate our approach by considering the following three subsidies:

- Agriculture: minimum prices for milk. These are EU-policies but we are interested in their environmental effects in the Netherlands.
- Energy: lower regulatory energy taxes for mass consumers as compared with small energy users.
- Transport: exemption of the Dutch part of excises on airline fuels.

The results in Table 2 show that substantial environmental effects result from each of these subsidies. This is particularly true for the subsidies with a point of incidence early in the production chain (Figure 2), namely the price support for milk and the tax exemption on kerosene.

Table 2. Environmental effects of indirect subsidies in the Netherlands

Type of subsidy	Subsidy in € bln	greenhouse gases (kton CO_2-eq.)	acidification (ton SO_2-eq.)	Photoch. Ozone (ton ethyl. eq.)	Eutrofication (ton phosphate eq.)	Land use (1000 ha.)
Price support milk[a]	1400	761–2925[b]	8400–32,100[b]	100–500[b]	7100–27,200[b]	115 – 215[b]
Tax break for major energy users	1568	811–2391[b]	197–566[b]	Na	na	Na
Tax exemption on kerosene	1200	1272	2433	208	695	Na

Notes:
a. Price support milk has been computed as the effect of a minimum price excluding the effects of Dutch milk quota. Including the quota would reduce the environmental effects.
b. For price support milk and tax break major energy users the ranges of outcomes under several variants are presented.
na = not applicable

Price support for milk

The minimum price for milk increases revenues for farmers directly and is characterised as an output subsidy (subsidy 4 in Figure 2). Producers receiving a minimum price increase their supply. In response, consumers reduce the quantity demanded so that a surplus results. To reduce this surplus, a system of EU milk quota has been introduced in the 1980s. We have corrected for the production limiting effect of the quota (see "adjust for policy environment" in Figure 1) by estimating the impact of the subsidy in a situation without quota. Our calculations show that the minimum price of milk increases the production of milk in the Netherlands by two million tons. Equation (1) demonstrates that the total environmental effect is determined by the additional production and the pollution intensity of milk production (equation (54) in Appendix I).

(1) $\Delta z = (q_s^g - q_e)\, Z_q$

with:
Δz = the environmental impact
q_s^g = (unrestricted) supply
q_e = supply at the equilibrium price in an unregulated market
Z_q = the pollution intensity of production

By means of a range of dairy supply elasticities of 0.26 to 1.00 (Boots *et.al*, 1997) a higher world market price is translated in a higher value of q_e. The EU is a major supplier of dairy products at the world market. The additional milk production that the EU produces as a result of the minimum price subsidy on milk significantly increases the world market supply and reduces the world market price. Several variants have been calculated with different combinations for world market prices (ranging from € 0.19 to € 0.24) and resulting in different values for q_e in order to take into account uncertainties with regard to these variables. The contribution to greenhouse gases ranges from more than 0.7 to nearly 3 megaton CO_2-equivalents.[6] The effects on photochemical ozone, eutrofication and land use are also substantial.

Tax break for energy

The subsidy on energy use consists of a low rate for major energy users and a special low rate for horticulture (compared to the standard rates for small firms and households). This subsidy concerns a producer subsidy in the final market (subsidy 4 in Figure 2). The impact runs through the product market. Given a production function including taxes and subsidies, the magnitude of the subsidy, the price elasticity of the equilibrium quantity and the pollution intensity of the production determine the environmental effect of a profit maximising producer, as reflected by equation 2 (see also equation (35) in Appendix I).

(2) $\Delta z = Z_q\, e_{p*}\, \Delta s$

with:
Δz = the environmental impact
Δs = the magnitude of the subsidy
e_{p*} = the price elasticity of the equilibrium quantity
Z_q = the pollution intensity of production

The parameters have been quantified on the basis of available studies and official data sources. Several variants have been calculated using different values for elasticities and for different energy tax rates, to examine the sensitivity of the procedure. The environmental effects range between 0.8 and 2.4 megaton CO_2-equivalents and between 197 and 566 ton SO_2-equivalents.

An excise exemption on kerosene
The exemption from excise duties on kerosene for airplanes (Dutch part) is a producer input subsidy through taxes (subsidy 2 in Figure 2). The method involves an equation (3) in which the environmental effect is related to five variables: magnitude of the input subsidy, price reaction of

[6] To compare: the Dutch effort to achieve the Kyoto targets is about 40 megaton CO_2-equivalents.

demand for air traffic, output price reaction of supply of air traffic, and the input price reaction of supply i.e. the impact of the kerosene price on air traffic supply (see equation (41) in Appendix I).[7]

(3) $$\Delta z = Z_q \left(\frac{D_p S_{w*}}{S_p - D_p} \right) \Delta s$$

with:
Δz = the environmental impact
Δs = the magnitude of the subsidy
D_p = price reaction of demand (for air travel)
S_p = output price reaction of supply
S_{w*} = input price reaction of supply
Z_q = the pollution intensity of production

The results show that the exemption leads to an increase of annual passenger kilometres by plane equal to 10 billion kilometres. This is 20 % of the total number of annual passenger kilometres. The environmental effects in the central variant are 1.3 megaton CO_2-equivalents and 2.4 kiloton SO_2-equivalents (cf. Table 2).

5. Conclusions

The results show that the method has a number of advantages and disadvantages. The main advantages are that it is based on traditional microeconomics and it's straightforward application to realize an initial assessment of first-order (economic and) environmental effects. In addition, the method is transparent in the sense that the influence of changes in parameter values can directly be traced, making sensitivity analysis easy. This allows the method to be useful for policy analysis, both *ex ante* (preparation) and *ex post* (evaluation). More complex, multisectoral (e.g., CGE) models can be used if it is suspected that indirect effects are significant, and may even exceed first-order effects.

A number of subsidies in the agricultural, energy and transport sectors have been analyzed to illustrate and test the method. These sectors contain subsidies that are suspected to have very distortive effects on the economy and to create sizeable environmental effects. For agriculture, the environmental effects of minimum prices for milk/dairy were calculated. In the energy sector, the relatively low energy tax for large-scale energy consumers was examined. In the transport sector, the exemption from the Dutch part of the excise taxes on aviation fuels was analyzed.

The applications show that sizable indirect subsidies can bring about relatively large environmental impacts (as summarized in Table 2). This is particularly true for the subsidies provided through the energy tax and milk price support. These subsidies interfere at an early stage in the production-consumption chain, allowing the impact to make it felt strongly and in a prolonged way. The excise tax exemption for aviation fuels also has a substantial environmental impact. In all cases the values of the elasticities of demand play an important role.

More research is needed to determine the parameter values accurately and within plausible boundaries. From this perspective it can be recommended to establish a database with subsidies and

[7] As there were no specific data on the price reactions of demand and supply, we have assumed that empirical price elasticities already incorporate the interaction between demand and supply. Additionally, we assume that the kerosene subsidy directly affects the output price by the share of fuel costs in total costs (α).The equation then becomes:

$$\Delta z = -Z_q \alpha e_p \frac{q}{w*} \Delta s$$

with e_p as the price elasticity of demand, q as the total activity and $w*$ as the (subsidised) price of kerosene.

price elasticities that can be easily and fairly quickly applied for use in the policy process. It is recommended that policy priorities given to the removal of subsidies be assigned according to the position of these subsidies in the production chain and according as well as to the magnitude of the related price elasticities of demand and supply.

Finally, path-dependence and lock-in factors may be sensitive to the context created by subsidies. Since lock-in is related to self-reinforcing phenomena, estimates of economic and environmental effects of subsidies generated by the method presented in this paper will often generate lower bounds to the actual magnitudes of these effects.

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Appendix I. Modelling the economic effect of subsidies

Three approaches to studying the environmental impact of indirect subsidies are proposed in this appendix. The approaches differ with regard to the economic information that is required to make the model operational. However, we will first present a simple model of the chain from subsidy to environmental impact to establish the framework of the analysis.

A basic model of the chain from subsidy to environmental impact

The following model of the chain from indirect subsidy to environmental effects shows the elements and relationships in the chain that have to be determined before the environmental effects of subsidies can be calculated.

$$Q = F(P(s), T(s), D(s)) \qquad (1)$$

$$S_{ij} = H_{ij}(I(s), T(s), Q, D(s)) \quad \textit{for relevant values of i,j} \qquad (2)$$

$$M_i = \sum_j w_{ij} S_{ij} \quad \textit{for relevant values of i} \qquad (3)$$

The symbols are defined as follows:

s = a subsidy or collection of subsidies
P = vector of production factors or inputs
I = infrastructure
T = technology
D = demand
Q = output
S_{ij} = environmental impact of effect j of general category i,
M_i = general environmental impact
F, *G*, H_{ij} = functions
w_{ij} = weighting factor for environmental effects ($\sum_j w_{ij} = 1$)

The first equation gives a relationship between indirect subsidies and demand, using as an example a subsidy (or collection of subsidies) that directly affects production factors, technology, and output or production level. The second equation is used to calculate specific environmental effects, such as CO_2 emissions, based on inputs, technology or output, or a combination of these three elements. The last equation uses weighting factors to aggregate the individual environmental effects and form general categories of environmental effects, such as the greenhouse effect (global warming potential). This last approach is in line with the EPI method as discussed in section 2.5.

A general model of the effect of subsidies on producers' decisions

Here a model is formulated of the effect of subsidies on the behaviour of producers, based on neo-classic microeconomic theory. This model is an extension of the basic model – optimisation of profit given a production function that describes a relationship between inputs and output – with taxes and subsidies. This extended model can be used to study certain changes that are caused by subsidies. Not all effects, however, can be traced with this model. For example, the effects of technological choices within companies, as well as the effects on a higher scale (such as sector structure, volume and composition of demand) are outside the framework of this model.

The company maximizes profit *W*

$$W = (1-t_w)[(p+s_p)Q - C - v + d_b] + v + d_v \qquad (4)$$

given production costs *C*

$$C = (p_K-s_K)K + p_L L + (p_I-s_I)I + (p_E-s_E)E \qquad (5)$$

and given the production relationship

$$Q = F(K,L,I,E) \qquad (6)$$

The symbols are defined as follows:
W = profit
C = total costs
Q = output
K = capital
L = labour
I = infrastructure
E = energy
p = output price
p_K = capital price
p_L = price of labour (wages)
p_I = price of infrastructure
p_E = price of energy
t_w = proportional tax on profit

The possible subsidies are:
$Q \leq Q_{max}$ volume regulation on output;
$p \geq p_{min}$ price guarantee on output;
$I = I^*$, and $p_I = 0$ public supply below cost price;
s_p = subsidy on the selling price;
s_K = subsidy on capital;
s_I = subsidy on infrastructure (public provision of goods below cost price);
s_E = subsidy on energy (e.g. exemption from Regulatory Energy Tax);
v = tax-free allowance;
d_v = tax-free direct subsidy;
d_b = direct subsidy for taxes (taxable).

Subsidy types (a) and (b) lead to extra conditions in the company's optimisation problem. The ideal way to determine the effect of these indirect subsidies would be to compare the relevant results of the optimisation problem (output or input, depending on the point of application of the environmental effects) with and without the extra condition in question. Since this is not possible in practice, a rough estimate of the effect will have to suffice in order to arrive at quantitative statements.

Rewriting (4) and (5) gives an insight into effective prices:

$$W = p^*Q - p_K^*K - p_L^*L - p_I^*I - p_E^*E + [t_w-s_w)]v + (1-t_w+s_w)d_b + d_v \qquad (7)$$

where:

$$p^* = (1-t_w+s_w)(p+s_p) \qquad (8)$$
$$p_K^* = (1-t_w+s_w)(p_K-s_K) \qquad (9)$$
$$p_L^* = (1-t_w+s_w)p_L \qquad (10)$$
$$p_I^* = (1-t_w+s_w)(p_I-s_I) \qquad (12)$$

represent the effective prices, i.e. the prices after taxes and subsidies.

Since in (7) the terms that include v, d_b and d_v do not contain Q, K, L, I or E, it follows immediately that the corporate decisions that focus on increasing or decreasing the supplied output volume or the volume of demand for an input are not affected by a tax-free allowance, nor by direct general subsidies. This is because these subsidies do not occur in the marginal rules that follow from the first order conditions for the optimisation problem. Obviously such indirect subsidies affect the level of profit.

The decisions about the demand for inputs and supply of output can then be derived from the optimisation problem as a function of the various subsidies. This provides the basis for the economic model. The first order conditions for the optimisation problem are:

$$\delta F/\delta x = (p_x-s_x)/(p+s_p) \qquad \textit{for } x = K,L,I,E \qquad (13)$$

If we specify the production function as a Cobb-Douglas relationship $AK^{ak}L^{al}I^{ai}E^{ae}$, and define B as $B=a_k+a_l+a_i+a_e$, then we obtain the following (output) supply and (input) demand functions:

$$Q = [A(p+s_p)^B(p_K-s_K)^{-ak}p_L^{-al}(p_I-s_I)^{-ai}(p_E-s_E)^{-ae}a_k^{ak}a_l^{al}a_i^{ai}a_e^{ae}]^{1/(1-B)} \quad (14)$$
$$K = Q^{1/B}a_k/(p_K-s_K)[p_L^{al}(p_I-s_I)^{ai}(p_E-s_E)^{ae}/(Aa_l^{al}a_i^{ai}a_e^{ae})]^{1/B} \quad (15)$$

with the analogous results for L, I and E.

A number of insights follow. Note first of all that effects on output and input depend on interactions between subsidies, given that there are different subsidies on the right-hand side in (14) and (15). It also follows from (14) and (15) that the supply (or output or volume of production) and the demand for inputs are not affected by a reduction in the proportional tax on profit (s_w). This tax does of course affect the level of profit.

Calculating the partial derivatives from the right-hand side in (14) to the various subsidies gives the marginal effects of subsidies on supply.

$$\delta Q/\delta s_p = BQ/[(p+s_p)(1-B)] \quad (16)$$
$$\delta Q/\delta s_K = a_kQ/[(p_K-s_K)(1-B)] \quad (17)$$
$$\delta Q/\delta s_I = a_iQ/[(p_I-s_I)(1-B)] \quad (18)$$
$$\delta Q/\delta s_E = a_EQ/[(p_E-s_E)(1-B)] \quad (19)$$

As expected, all effects in (16) to (19) are positive (assuming for inputs that the subsidy level is below the market price). The expressions also offer the possibility of calculating the magnitude of the effects, if the necessary data is available.

Calculating the partial derivatives from the right-hand side in (15) to the various subsidies gives the marginal effects of subsidies on the demand for inputs:

$$\delta K/\delta s_p = K/[(p+s_p)(1-B)] \quad (20)$$
$$\delta K/\delta s_K = a_kK/[(p_K-s_K)B(1-B)] + K/(p_K-s_K) \quad (21)$$
$$\delta K/\delta s_I = -a_iK/[(p_I-s_I)B(1-B)] - (a_i/B)\ (p_I-s_I)^{(ai-B)/B}[p_L^{al}(p_E-s_E)^{ae}/(Aa_l^{al}a_i^{ai}a_e^{ae})]^{1/B} \quad (22)$$
$$\delta K/\delta s_E = -a_EK/[(p_E-s_E)B(1-B)] - (a_e/B)\ (p_E-s_E)^{(ae-B)/B}[p_L^{al}(p_I-s_I)^{ai}/(Aa_l^{al}a_i^{ai}a_e^{ae})]^{1/B} \quad (23)$$

with the analogous calculations for the derivatives of I and E (and also L if it can be directly linked to environmental effects, which is not obvious). The signs of the effects in (20) and (21) are positive, which is as expected. The signs in (22) and (23) are negative, which is also as expected because price cross-effects are negative in normal practice with inputs that can be substituted (as is assumed with the choice of the Cobb-Douglas production function).

It is now possible to determine the extent of the effect of the subsidy. This depends on five variables:

- The magnitude of the subsidy (s_j for $j = p, K, I$ or E).
- The production function parameters (A; a_j for $j = k, l, i$ or e; and B).
- The magnitude of the relevant input (Q, K, or I).
- The output price and the input prices (p and p_j for $j = p, K, I$ or E).
- The effect of the relevant inputs and output on the environmental impact (see equation (2)).

Tax-free allowance for the output price (low rate of VAT for consumers)

If no information is available about the production function, then an analysis can immediately start at the level of demand and supply functions. This is the point of departure of the following two approaches. They are based on interaction between final demand and supply of a particular product, which introduces demand effects in the analysis. Partial equilibrium analyses show the effects of an indirect subsidy, such as a tax-free allowance, on prices and volumes of output and input. The prices are determined by the interaction between demand and supply. Two types of tax-free allowances are considered, namely on the output price and on the input price.

We start by defining demand and supply functions in equations 24 and 25:[8]

$q_d = D(p^*, p_i, y)$ (24)

We assume that a tax-free allowance – i.e. an indirect subsidy s – applies for the product in question, so that $p^* = p - s$, where p is the price to which the subsidy is applied. The following also applies: $D_{p*}<0$; $D_y>0$; $D_{pi}<0$ (complementary goods), or $D_{pi}>0$ (substitutes).

$q_s = S(p, w_i)$ (25)

where:
$S_p > 0; S_{w_i} < 0.$

The symbols are defined as follows:
q = equilibrium volume;
q_d = volume of demand;
q_s = volume of supply;
p = price of the product to be subsidised;
s = subsidy in the form of a low rate of VAT;
p^* = effective price of the product (including subsidy);
p_I = prices of other complementary or substitutable products;
y = aggregated income of the consumers;
w = input price.

The equilibrium condition is:

$q = q_d = q_s$ (26)

which is equivalent to:

$D(p - s, p_i, y) = S(p, w_i)$ (27)

In order to find the effect on the equilibrium price, the equilibrium volume and the external effect, the total differential of (27) is determined:

$$D_{p*}(dp - ds) + D_{p_i}dp_i + D_y dy - S_p dp - S_s ds - S_{w_i}dw_i = 0 \quad (28)$$

The subsidy has an effect on the equilibrium price and the equilibrium volume. We can therefore suppose that $dp_i = dy = dw_i = 0$, which leads to:

$D_{p*}(dp - ds) - S_p\,dp = 0$ (29)

It then follows that:

$$\frac{dp}{ds} = \frac{D_{p*}}{D_{p*} - S_p}. \quad (30)$$

Here we are mainly interested in the effect of the subsidy on the equilibrium volume since that is the point of application for environmental effects in this model. This effect can be determined as follows:

[8] Demand and supply curves are derived from maximum-utility consumer behaviour and profit-maximising producer behaviour. Functions with a sub-index indicate a first derivative to the variable in the index.

$$\frac{dq}{ds} = \frac{dq}{dp^*}\frac{dp^*}{ds} = D_{p^*}\left(\frac{dp}{ds} - 1\right) = \frac{D_{p^*}S_p}{D_{p^*} - S_p} . \qquad (31)$$

Note that the sign here is positive. This means that a higher subsidy (lower VAT) stimulates consumption and thereby production of the product in question.

We next assume a positive dependence of an environmental effect *z* on the produced equilibrium volume, so that:

$$z = Z(q) \qquad (32)$$

where:
$Z_q > 0$.

From (31) and (32) it can be derived that the environmental effect of the subsidy is equal to:

$$\frac{dz}{ds} = \frac{dz}{dq}\frac{dq}{ds} = Z_q \frac{D_{p^*}S_p}{D_{p^*} - S_p} . \qquad (33)$$

The effect in (33) is a marginal effect that can be considered the average effect for relatively small changes. In other words, if the magnitude of the subsidy is Δs, then the environmental effect is equal to:

$$\Delta z = Z_q \frac{D_{p^*}S_p}{D_{p^*} - S_p} \Delta s . \qquad (34)$$

The sign here is positive, i.e. the effect of the subsidy (a low rate of VAT) on the environmental impact of production is positive. The extent of this strengthening effect of the subsidy depends on four variables:

- The magnitude of the subsidy;
- The price reaction in the demand (D_{p^*});
- The price reaction in the supply (S_p);
- The pollution intensity of production (Z_q).

The second variable in this list depends on the type of product (e.g. necessity or luxury) and on consumers' preferences. The third element reflects the production costs of the company (or sector), and indirectly also substitution possibilities in the input mix, availability of alternative production techniques, and the competitive situation on the sales market.

Note that (34) can also be expressed in terms of price elasticities of demand and supply. Most price elasticities already include the interaction between demand and supply. In this case a more simple equation can be used:

$$\Delta z = (Z_q e_{p^*} q^* / p^*)\Delta s . \qquad (35)$$

where e_p is the price elasticity of the equilibrium volume. The extent of this strengthening effect of the subsidy depends on four variables:

- The magnitude of the subsidy;
- The price elasticity of the equilibrium volume (e_{p^*});
- The equilibrium volume and price (q^* and p^*);
- The degree of pollution from production (Z_q).

Tax-free allowance for the input price

The point of departure is different if we want to study the environmental effect of a price on production inputs or factors. If we start immediately with the equilibrium condition, then a subsidy s on the input price *w* leads to:

$$D(p, p_i, y) = S(p, w^*). \tag{36}$$

where $w^* = w - s$. From the total differential and logical price changes it then follows that:

$$D_p dp - S_p dp - S_{w^*} ds = 0. \tag{37}$$

Which can be rewritten as:

$$\frac{dp}{ds} = -\frac{S_{w^*}}{S_p - D_p}. \tag{38}$$

The effect of the subsidy on the equilibrium volume is then:

$$\frac{dq}{ds} = \frac{dq}{dp}\frac{dp}{ds} = \frac{D_p S_{w^*}}{D_p - S_p}. \tag{39}$$

The environmental effect changes as follows:

$$\frac{dz}{ds} = \frac{dz}{dq}\frac{dq}{ds} = Z_q\left(\frac{D_p S_{w^*}}{D_p - S_p}\right). \tag{40}$$

If the magnitude of the subsidy is equal to Δs, then the environmental effect is equal to:

$$\Delta z = Z_q\left(\frac{D_p S_{w^*}}{S_p - D_p}\right)\Delta s. \tag{41}$$

The sign here is positive. In other words, a given change in a tax-free allowance for an input factor to a polluting production process results in greater environmental damage. The extent of that damage depends on five variables:

- The magnitude of the subsidy;
- The price reaction in the demand (D_p);
- The output price reaction in the supply (S_p);
- The input price reaction in the supply (S_{w*});
- The pollution intensity of production (Z_q).

Finally, note that it is assumed that the market price w of the input is not affected by the subsidy. If it were affected, then a more complicated expression than (41) would result and more information would obviously be needed for the calculations.

Effect of subsidies on consumer decisions

A model is presented here that reflects the effect of subsidies on consumer decisions. Consumer subsidies are to be expected in particular in the transport sector. Think of the flat-rate allowance for travel costs or the exemption from VAT on airline tickets, for example. As with the model for producers' decisions, we will first consider the general problem and then a specific example using functional specifications of the utility function.

The consumer maximizes utility subject to the parameter condition of his budget. In general terms, the utility function can be expressed as follows:

$$U = U(x_1, \ldots, x_k, \ldots, x_n) \qquad (42)$$

The budget restriction is as follows:

$$(1 - t_y)(y - f) = \sum_{i=1}^{n} (p_i - s_i)\, x_i \qquad (43)$$

where:
U = utility;
y = income;
t_y = income tax;
f = subsidy via a flat-rate allowance;
x_i = consumption of product i ($i = 1, \ldots, n$);
p_i = price of product i;
s_i = price subsidy on product i;

Working out this maximisation problem yields the following demand functions:

$$x_i = D_i(p_1 - s_1, \ldots, p_k - s_k, \ldots, p_n - s_n, y, f, t_y) \qquad (44)$$

with:

$$\frac{\delta x_i}{\delta y} > 0 \qquad \frac{\delta x_i}{\delta f} > 0 \qquad \frac{\delta x_i}{\delta t_y} < 0 \qquad (45)$$

Let us suppose that not all goods are subject to a subsidy: $s_i = 1$ for $i = k$ and $s_i = 0$ for $i \neq k$. In the case of substitution between the goods the following applies:

$$\frac{\delta x_i}{\delta s_k} > 0 \; for \; i = k \qquad (46a)$$

$$\frac{\delta x_i}{\delta s_k} < 0 \; for \; i \neq k \qquad (46b)$$

In the case of complementary goods the following applies:

$$\frac{\delta x_i}{\delta s_k} > 0 \; for \; all \; i \qquad (47)$$

We will work this out by specifying a Cobb-Douglas production function for 2 products, e.g. public transport (x_1) and subsidised private use of cars (x_2). The utility function is:

$$U = x_1^{a_1} x_2^{a_2} \qquad (48)$$

This function is maximised under the parameter condition of the budget restriction:

$$(1 - t_y)(y - f) = p_1 x_1 + (p_2 - s_2) x_2 \qquad (49)$$

Solving this system gives the demand functions for x_1 and x_2:

$$x_1 = \frac{a_1(1 - t_y)(y - f)}{(a_1 + a_2) p_1} \qquad (50a)$$

$$x_2 = \frac{a_2(1 - t_y)(y - f)\, y}{(a_1 + a_2)(p_2 - s_2)} \qquad (50b)$$

Differentiating to s_2 only affects the demand for the 'own' product, x_2. A larger subsidy leads to a larger demand for the product on which the subsidy is given, as is shown by the following partial derivative:

$$\frac{\delta x_2}{\delta s_2} = \frac{a_2(a_1 + a_2)(1 - t_y)(y - f)}{\{(a_1 + a_2)(p_2 - s_2)\}^2} > 0 \qquad (51)$$

Differentiating to the flat-rate allowance f affects the demand for both products:

$$\frac{\delta x_1}{\delta f} = \frac{a_1(t_y + 1)}{(a_1 + a_2) p_1} > 0 \qquad (52a)$$

$$\frac{\delta x_2}{\delta f} = \frac{a_2(t_y + 1)}{\{(a_1 + a_2)(p_2 - s_2)\}^2} \qquad (52b)$$

The Cobb-Douglas specification implies that the cross-elasticities are 0. In transport, for example, low values for such elasticities can be substantiated based on the fact that the transfer from private to public transport is difficult due to lock-in effects.

The connection with the environmental impact is made via equation (2) in Appendix I:

$$\Delta z = \Delta s \; \delta x_i / \delta s_k \; Z_q \, . \qquad (53)$$

The extent to which tax affects the environmental depends on the following variables:

- The magnitude of the subsidy (Δs);
- The effect of the subsidy on demand ($\delta x_i/\delta s_k$). This effect depends on the assumed functional specification of the utility function. Here there is a choice between various equations. It is also possible for a subsidy to produce cross-effects. In that case the effects should be added together. However, in practice this is of limited relevance since the cross-effects are relatively small compared to the 'own' effects.
- The degree of pollution from use or production of the consumed product to which the subsidy applies (Z_q).

Minimum prices

As shown in Figure I.1, a producer reacts to a minimum price $p_g > p_e$ (= market equilibrium price) by producing more and offering more of the product for sale than the equilibrium volume (q_e). Consumers on the other hand reduce the volume of demand for the product because the price is higher. This creates a surplus that is accompanied by an extra subsidy transfer compared with the situation where q_e is offered for sale at price p_g. The total subsidy transfer is cdp_gp_e.
The environmental effect of the price guarantee is expressed as follows:

$$\Delta z = (q^s{}_g - q_e)\, Z_q \qquad (54)$$

The volume effect (first part of the term on the right-hand side) can be derived from Figure I.1. The following information is required to apply this equation:

- Supply with price guarantee, i.e. in the current situation ($q^s{}_g$);
- Supply at free market price (q_e). This requires hypothetical data, which in some cases can be based on earlier studies (e.g. with CGE models). Note that if the applicable world market price (p_w) is not equal to the domestic free market price (p_e), the supplied volume q_e in the equation should be replaced by q_w;
- The degree of pollution from production (Z_q).

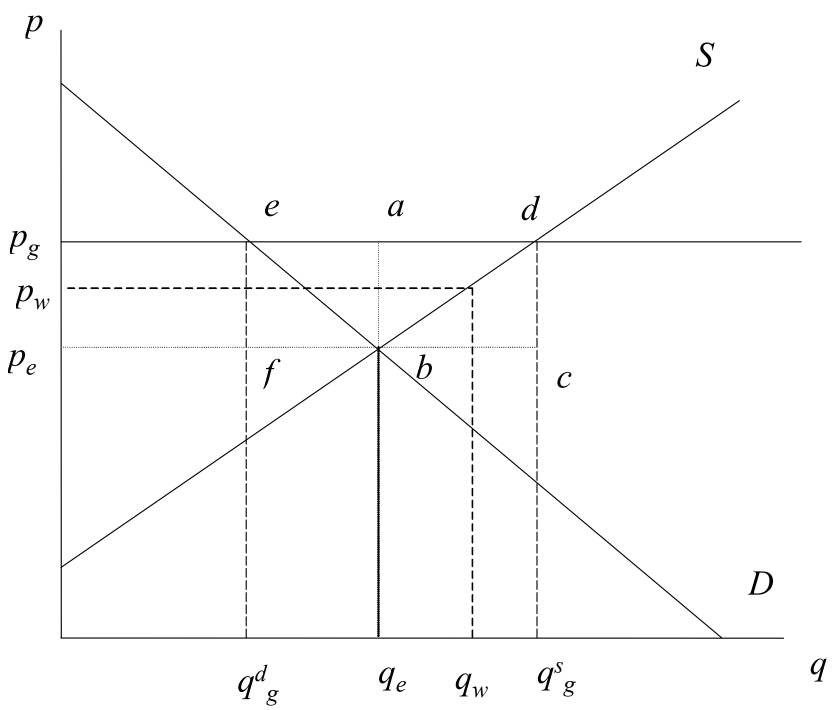

Figure I.1. The economic effect of minimum prices.

Legend:
q_i = volume of the product (volume of supply or demand);
p_i = price of the product;
D = demand curve;
S = supply curve (marginal private costs).

Appendix II Weighting factors used to calculate environmental indicators

Table II.1 contains the weighting factors that are used to calculate environmental indicators. These factors are based on VNCI (2001).

Table II.1. Weighting factors for calculating environmental indicators

	Greenhouse effect	Acidification	Photochemical ozone creation	Eutrophication
CO_2	1			
N_2O	310			
CH_4	21		0.006	
NO_x (as NO_2)		0.41	0.028	0.13
SO_2		1		
NH_3		1.30		0.35
VOC			0.5*	
CO			0.027	
Phosphate				1
Nitrate				0.1