MEMORANDUM

No 26/2001

Climate policies and induced technological change: Which to choose the carrot or the stick?

By
Snorre Kverndokk, Knut Einar Rosendahl and Thomas F. Rutherford

ISSN: 0801-1117

Department of Economics
University of Oslo

This series is published by the
University of Oslo
Department of Economics

P. O.Box 1095 Blindern
N-0317 OSLO Norway
Telephone: + 47 22855127
Fax: + 47 22855035
Internet: http://www.oekonomi.uio.no/
e-mail: econdep@econ.uio.no

In co-operation with
The Frisch Centre for Economic Research

Gaustadalleén 21
N-0371 OSLO Norway
Telephone: +47 22 95 88 20
Fax: +47 22 95 88 25
Internet: http://www.frisch.uio.no/
e-mail: frisch@frisch.uio.no

List of the last 10 Memoranda:

No 25	By Olav Bjerkholt: Tracing Haavelmo's steps from Confluence Analysis to the Probability Approach. 33 p.
No 24	By Sverre A.C. Kittelsen, Guri Galtung Kjæserud and Odd Jarle Kvamme: Errors in Survey Based Quality Evaluation Variables in Efficiency Models of Primary Care Physicians. 23 p.
No 23	By Ove Wolfgang: Eco-Correlation in Acidification Scenarios. 52 p.
No 22	By Øystein Kravdal: The High Fertility of College EducatWomen in Norway: An Artefact of the 'Piecemeal Approach'. 14 p.
No 21	By Yngve Willassen: On the Economics of the Optimal Fallow-Cultivation Cycle. 19 p.
No 20	By Michael Hoel: Allocating greenhouse gas emissions among countries with mobile populations. 14 p.
No 19	By Tore Nilssen and Lars Sørgard: Who Are the Advertisers? 17 p.
No 18	By Tore Nilssen and Lars Sørgard: The TV Industry: Advertising and Programming. 35 p.
No 17	By Michael Hoel: Domestic inefficiencies caused by transboundary pollution problems when there is no international coordination of environmental policies. 21 p.
No 16	By Steinar Holden: Monetary policy and nominal rigidities under low inflation. 41 p.

A complete list of this memo-series is available in a PDF® format at:
http://www.oekonomi.uio.no/memo/

Climate policies and induced technological change: Which to choose the carrot or the stick?[i]

by

Snorre Kverndokk[ii], Knut Einar Rosendahl[iii] and Thomas F. Rutherford[iv]

October 2001

Abstract

Policies to reduce emissions of greenhouse gases such as CO_2 will affect the rate and pattern of technological change in alternative energy resources and other production processes. Imperfections in markets for non-polluting technologies imply that a decentralised economy does not deliver a socially optimal outcome, and this could justify policy interventions such as subsidies. This paper considers the welfare effects of technology subsidies as part of a carbon abatement policy package. We argue that the presence of spillovers in alternative energy technologies does not necessarily imply that subsidy policies are welfare improving. We illustrate this point in the context of a general equilibrium model with two forms of carbon-free energy, an existing "alternative energy" which is a substitute for carbon-based fuels, and "new vintage energy" which provides a carbon-free replacement for existing energy services. Subsidisation of alternative energy on the grounds of spillover effects can be welfare-worsening if it crowds-out new vintage technologies.

JEL classification: *D58, H21, O30, Q42.*

Keywords: *Induced technological change; Climate change policies; Policy instruments; Computable general equilibrium models.*

[i] This paper is partly financed by The Norwegian Research Council. Snorre Kverndokk and Knut Einar Rosendahl are indebted to the hospitality of Department of Economics, University of Colorado at Boulder while working on this project. We are indebted to comments from Michael Hoel and seminar and conference participants in State College, Boulder, Oslo and Southampton.
[ii] Corresponding author. E-mail: snorre.kverndokk@frisch.uio.no, fax: +4722958825, tel.: +4722958811, address: Ragnar Frisch Centre for Economic Research, Gaustadalléen 21, 0349 Oslo, Norway.
[iii] Research Department, Statistics Norway, P.O. Box 8131 Dep., 0033 Oslo, Norway.
[iv] Department of Economics, University of Colorado at Boulder, Boulder, Colorado 80309-0256, USA.

1. Introduction

The development of non-fossil renewable energy resources is important for future carbon emissions. As shown by Chakravorty et al. (1997), if the technological change for one of these resources, solar energy, follows the historical rates, carbon emissions could peak before the middle of the century in a business as usual (BAU) path, i.e., in a world without climate agreements. Other models assume that the business as usual carbon emissions paths will increase monotonically over the century, see, e.g., the IS92a scenario (IPCC, 1992). Thus developments in renewable (non-fossil) energy sources are very important for the BAU emission paths and, therefore, the costs of implementing a climate treaty and the process of negotiating further treaties (extending the Kyoto Protocol). The development of alternative energy sources is also important for fossil fuel producing countries, as the price of oil and gas, and therefore petroleum wealth, will be dependent of the price of alternative energy sources (see, e.g., Kverndokk et al., 2000). However, in many energy models the development of new energy resources is assumed exogenous and unaffected by events like an increasing oil price or a climate treaty. A better understanding of how technological change is induced by for instance carbon taxes, would give improved knowledge on optimal abatement, the use of policy instruments, and how these interact with markets.

Several researchers have emphasised that climate policies and the rate of technological change are connected, see, e.g., Bovenberg and Smulders (1995), Schneider and Goulder (1997), Grübler and Messner (1998), Goulder and Schneider (1999) and Goulder and Mathai (2000). The argument is that public policies affect the prices of carbon based fuels, which in turn affect incentives to undertake research and development (R&D) aimed at bringing alternative fuels to market earlier at a lower cost and/or at a higher capacity. These new low-carbon products could represent existing or entirely new energy services. In addition, higher fuel prices may induce new production methods that require less of any kind of fuel. Technology may also improve through learning-by-doing, i.e., producers gain experience in using alternative energy services or energy-conserving processes (see, e.g., Grübler and Messner, 1998). Stimulation of such activities, either directly through subsidies or indirectly through taxing competing activities, may therefore influence the technological process. The important consequence of these effects is that technological change in the BAU scenario and in the policy scenario will differ.

One important question where ITC plays a role concerns the optimal policy mix between taxing carbon emissions and subsidising carbon-free technologies. If there are no market failures apart from the externalities connected to pollution, the cost-minimising policy is to use carbon taxes alone as they directly target the market imperfection. Using technology subsidies as the only policy instrument will give higher costs of reaching the emission target. Even though subsidies may correct the relative price between carbon-based and carbon-free fuels, the relative price of energy is too low. However, if there also are technology spillovers, the optimal policy can be to use both carbon taxes and subsidies. This follows from the theory of policy goals and means (see, e.g., Johansen, 1965). The optimal policy mix depends on how the technology spillovers arise and how ITC occurs.

The aim of this paper is to investigate how the welfare implications of technology subsidies and carbon taxes depend on the characteristics of energy technologies. Our paper is related to Goulder and Schneider (1999) who, in addition to other issues, study how technology subsidies can reduce the costs of CO_2 abatement if there are knowledge spillovers by R&D investments. One key limitation of the paper by Goulder and Schneider (1999), however, is that the alternative energy support is calibrated to historical value shares; i.e., no new technology is brought into the market as a result of climate policies, and there is a smooth transition between the production and use of the alternative energy and the conventional energy (fossil fuels). We believe that the solution to substantial greenhouse gas reduction is more likely to result from the development of an entirely different set of technologies. One important policy question is then whether subsidising an existing technology may delay or prevent the introduction of new technologies thereby resulting in future welfare losses. Also, to what extent does the relative merits of taxes versus subsidies depend on the characteristics of a new technology? Will the optimal subsidy of an existing alternative energy source change if there are possibilities of new technologies coming into force, and how is this dependent on spillovers from the new technology?

In a first best world with perfect information, the government should commit to subsidise all production processes that create positive spillovers. In this case, a potential producer as well as the government knows if the product will create spillovers or not. Thus, the potential producer takes into account the effects of the subsidy on its production costs, and it will start producing as soon as the new product becomes *socially profitable*. In this case, positive spillovers from *existing* technologies as well as *potential* should be fully subsidised.[1] However, it seems less likely that the government will commit to subsidising new products. Rigidities and slow political systems may make it hard to remove old subsidies, as well as to introduce new ones. Also, with imperfect information the producer may not be aware of that his product provides positive spillovers, and even if he does, the government may not be convinced. Thus, in a second best world, the potential producer will only consider private costs in the decision to develop and produce. In this case, subsidising the existing alternative energy product may delay or reduce the production of a competing energy product as compared to the socially optimal level.

We use a static, computable general equilibrium (CGE) model to develop a qualitative understanding of how instrument choice is influenced by the nature of energy supply technologies and the spillovers from these activities. In our model, when the only spillover effects arise in the existing alternative energy sector, then the presence of new technologies does not change the optimal subsidy. However, if climate policy induces new technologies to enter the market and these also have positive spillovers, then the second-best optimal subsidy to existing alternative energy may be zero, or even negative. In short, an optimal subsidy choice demands that the government pick *all and only* those firms that are responsible for external benefits.

---

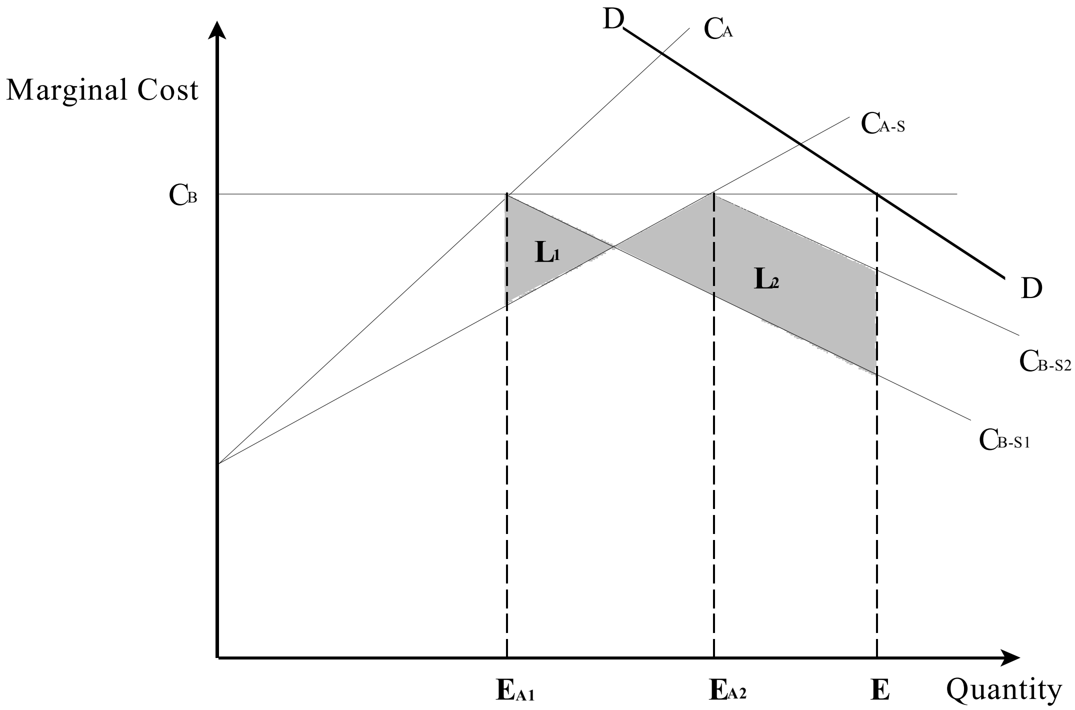
[1] There are, however, cases where a subsidy may create a welfare loss. One example is given in footnote 3.

The remainder of the paper is organised in the following way. In the next section we give a simple illustration of the instrument choice question in a partial equilibrium context. In section 3 we present a theoretical general equilibrium model and outline some implications. In section 4 the theoretical model is parameterised and numerical results are presented. Section 5 concludes.

2. A simple illustration of the optimal policy mix

To illustrate the ideas, we start with a simple graphical model. Consider a competitive economy with two existing energy products. One is conventional energy (E_C) produced by fossil fuels, and the other is a non-fossil alternative energy product (E_A). Further, assume that there is a carbon constraint in the economy, so that the consumption of E_C is fixed. In Figure 1, we can then draw the market for *non-fossil energy*, where D is the *residual demand* curve for energy, i.e., the total demand for energy minus the use of E_C. Let C_A be the supply curve for E_A, which reflects the *private marginal costs* of producing alternative energy. To simplify, we assume that there are positive spillovers from the alternative energy sector to the rest of the economy, but *not* within the sector itself or to other energy producers. The spillovers are increasing in production. Thus, the *social marginal costs* of alternative energy are lower than the private marginal costs, as illustrated by the curve C_{A-S}.

A backstop technology (E_B) is assumed to provide an unlimited supply of energy services at a constant *private* marginal cost, as represented by C_B. E_B is a perfect substitute to E_A. For the purpose of illustrating one potential pitfall associated with energy subsidies, we assume similar externalities as for the alternative energy products, which are ignored by competitive producers. Hence, the social cost is lower than the private cost in this sector, indicated by the marginal social costs C_{B-S1} and C_{B-S2}.



Key:

D-D	Market demand for non-fossil energy
C_A	Marginal private cost of alternative energy
$C_{A\text{-}S}$	Marginal social cost of alternative energy
C_B	Marginal private cost of backstop energy
$C_{B\text{-}S1}$	Marginal social cost of backstop energy – alternative energy = E_{A1}
$C_{B\text{-}S2}$	Marginal social cost of backstop energy – alternative energy = E_{A2}
L_1	Efficiency *increase* in alternative energy with subsidy to alternative energy
L_2	Efficiency *decrease* in backstop energy with subsidy to alternative energy
L_2-L_1	Net social cost of a subsidy to alternative energy

Figure 1: The social costs of subsidies to alternative energy production.

The competitive outcome in the non-fossil energy market finds alternative energy production equal to E_{A1} and backstop production equal to E-E_{A1}. We now study the effects of subsidising E_A. If the alternative energy sector is subsidised at a level such that social marginal cost equals market price, then E_A production increases to E_{A2} while E_B production declines to E-E_{A2}. This level of subsidy to alternative energy would be socially optimal in the absence of spillovers from backstop production. However, when there are positive spillovers both from E_A as well as from E_B production, the subsidy may be welfare worsening. To see this, consider Figure 1 once more. When the subsidy is introduced, social costs are reduced by the triangle L_1 and increased by the area L_2. This reflects that the spillovers from the alternative energy sector are internalised, but spillovers from the backstop are unrewarded. It is ambiguous whether L_1 or L_2 is bigger. If $L_1 > L_2$, the society gains from the subsidy. However, the gain could be even higher if a lower subsidy was introduced.[2] If $L_1 < L_2$, society loses from a subsidy which fully compensates spillovers in the alternative energy sector, and the optimal subsidy in this second best economy could actually be zero or even negative.

This shows that subsidies intending to internalise spillover effects in the alternative energy sector may increase the costs to the society, as spillover gains from the backstop technology, that are not valued in the market, are reduced. Therefore, subsidies to the alternative energy sector should at least be less than if no backstop spillovers were present, and they should possibly be eliminated.[3]

The above conclusions are based on a very simple partial equilibrium model. Will the results still hold if we relax some of the assumptions above and introduce a general equilibrium framework? To answer this, and to analyse the welfare effects and the optimal combination of policy instruments in a more general setting, we work with a numerical general equilibrium model. In this model we will complicate the picture by introducing

- spillover effects within the sectors

---

[2] It can be shown that the necessary condition for minimising the social costs is $C_{A-S}(E_A) = C_{B-S}(E_B)$, i.e., equal marginal costs for the last unit produced both of E_A and E_B. The optimal subsidy in this second best economy should be set so that this condition is fulfilled.

[3] There are also cases where a subsidy to the alternative energy sector can be welfare reducing even if the alternative energy sector creates positive spillovers and the backstop production does not. One example is a situation with falling private and social marginal costs in alternative energy production (economies of scale), and low and constant marginal costs of backstop production. The single producer may, however, consider unit costs of E_A as given (i.e., marginal costs are constant and equal to unit costs) and higher than the unit costs of E_B. In this case we may have backstop production only with no subsidies, and alternative energy production only with subsidies. The total social costs may, however, be higher in the latter case. A graphical illustration is available from the authors. We are indebted to Michael Hoel for pointing this out to us.

- spillover effects from backstop production to the alternative energy sector and vice versa,
- imperfect substitution between E_B and E_A.

This model is outlined and analysed in the following two sections.

3. The algebraic formulation of the static model

A static general equilibrium model for a closed competitive economy is structured as follows. There is one macro aggregate produced by the input factors capital, labour and energy. Energy produced with existing technologies are of two types: (i) conventional, carbon-based energy (i.e., fossil fuels) and (ii) alternative, carbon-free energy (e.g., wind power). Energy from new technologies, i.e., *backstop energy*, may become economically profitable with climate policies, as the price of existing energy products will increase.[4] We assume that there may be positive spillover effects from the production of alternative and/or backstop energy. In our static setting, spillovers arise through learning-by-doing, by assuming that increased production of alternative or backstop energy increases the productivity of workers in these sectors. In the short run, the only way to increase production in these sectors is to employ more labour. Thus, there is a one-to-one relationship between the number and productivity of workers.

Below we describe the spillover model in more detail. We first present a constant returns to scale (CRTS) version of the model which shares the same features but excludes learning-by-doing. Rather than presenting general functional forms, we present the functional forms used in the numerical model to better explain its results.

3.1. The constant returns to scale model

The production of the aggregate output (the macro good), Y, is characterised by the following nested constant-elasticity-of-substitution (CES) production function:

[4] As uncertainty is not explicitly modelled, the backstop technology may be thought of as a technology that actually is available but is yet not utilised.

(1) $Y = \left[\alpha E^{\rho} + (1-\alpha) K_Y^{\beta\rho} L_Y^{(1-\beta)\rho}\right]^{\frac{1}{\rho}}$

in which E represents aggregate energy inputs, K_Y is the capital stock (fixed in the short run), and L_Y is labour input. α and β are positive parameters, each with a value less than 1, and the elasticity of substitution between energy and value added is defined as $\sigma = 1/(1 - \rho)$.

Aggregate energy inputs are the sum of supply from extant and new vintage (backstop) technologies:

(2) $E = \phi E_C^{\theta} E_A^{1-\theta} + E_B$

in which E_C represents conventional carbon energy measured in carbon units, E_A represents existing alternative energy and E_B represents new vintage (backstop) energy.[5] Both alternative and backstop energy are carbon-free. ϕ and θ are positive parameters, and $\theta < 1$. The existing alternative energy is assumed to be an imperfect substitute to conventional energy, while the backstop energy is assumed to be a perfect substitute to the aggregate of other energy sources, but *not* to a single existing energy product.

Labour and capital are the input factors in the production functions for conventional and alternative energy. These are specified as follows:

(3) $E_C = \phi_C K_C^{\theta_C} L_C^{(1-\theta_C)}$

(4) $E_A = \phi_A K_A^{\theta_A} L_A^{(1-\theta_A)}$

[5] Alternatively, the energy aggregate could be modelled as a CES aggregate of existing energy products (E_C and E_A) and the backstop (E_B). The linear relationship in (2) could then turn out as a special case if we assume an infinite substitution elasticity between the two types of energy.

As all capital stocks (K_Y, K_A and K_C) are fixed in the static model, there are rising marginal costs of supply of E_C and E_A. New vintage energy supply is, however, proportional to employment, reflecting constant marginal costs:

(5) $E_B = \phi_B L_B$

The labour market is cleared through a uniform wage:

(6) $L = L_Y + L_A + L_B + L_C$

In a competitive equilibrium, energy producers maximise profit. Thus, macro firm *i* chooses the composition of alternative and conventional energy so as to minimise the unit cost of the energy composite, at any level of $E_i - E_{B,i}$. That is, with $E_i - E_{B,i} = (E_i - E_{B,i})^*$, we have:

(7) $p_E = \min \frac{(p_C E_{C,i} + p_A E_{A,i})}{(E_i - E_{B,i})^*}$ s.t. $\phi E_{C,i}^{\theta} E_{A,i}^{(1-\theta)} = (E_i - E_{B,i})^*$

The possibility of backstop production places an upper bound on the price of the energy aggregate, as E_B is a perfect substitute to this aggregate. This follows from the first order condition for profit maximisation in backstop production, i.e., $p_B = \frac{w}{\phi_B}$. Thus, we have:

(8) $p_E \leq \frac{w}{\phi_B}$

The inequality holds as an equality for $E_{B,i} > 0$.

When there is a carbon constraint, the production of conventional energy, E_C, is fixed, i.e., $E_C = a\overline{E}_C$ where $0 < a < 1$ and $\overline{E}_C$ is the BAU level. Thus, the composite of existing energy technologies, $E - E_B$, is a function of the labour input in the alternative energy sector as this is the only flexible input factor:

$$(9)\quad E - E_B = \phi E_C^{\theta} E_A^{(1-\theta)} = \phi(a\overline{E}_C)^{\theta}\left(\phi_A K_A^{\theta_A} L_A^{(1-\theta_A)}\right)^{(1-\theta)} = f(L_A)$$

Profit maximisation requires that the value of the marginal product of increasing L_A should equal its costs, i.e.,

$$(10)\quad p_E \frac{\partial f(L_A)}{\partial L_A} = w$$

or

$$(11)\quad \frac{\partial f(L_A)}{\partial L_A} = \frac{w}{p_E}$$

When the backstop energy is produced, we see from (8) that $\frac{w}{p_E} = \phi_B$. Thus, for a given carbon constraint, the fixed marginal product of labour in the backstop sector determines the marginal product of labour in the alternative energy sector.

3.2 The model with spillovers

There is much evidence of learning-by-doing effects in alternative energy production. Grübler and Messner (1998) refer to learning curves for photovoltaic costs in Japan, where unit costs are reduced by over 30 per cent per doubling of installed capacity. Although some of the cost reduction is due to R&D investments, there is clear evidence that experience also is a vital factor. Moreover, as workers switch jobs, they take their skills with them, producing spillover effects (Gustavsson et al., 1999).

In the spillover model, we assume that there are external economies of scale, as more labour employed in the alternative (and/or backstop) sectors leads to higher rates of labour productivity within these sectors. Thus, productivity grows through learning-by-doing. Moreover, the learning effect is assumed to be external to the firm, i.e., a higher labour productivity in one firm within these sectors has positive spillover effects on the labour productivity for all firms in these sectors.

If we let ℓ_A and ℓ_B be the *productivity-adjusted* supplies of labour to the alternative and backstop energy sectors, the outputs in these sectors are given by:

(12) $E_A = \phi_A K_A^{\theta_A} \ell_A^{(1-\theta_A)}$

(13) $E_B = \phi_B \ell_B$

The quality of a worker in the alternative and backstop energy sectors is denoted λ, which is set equal to 1 in the BAU scenario (i.e., for the alternative energy sector, there is no backstop production in this scenario). Learning-by-doing or spillover effects are determined by a parameter $\gamma \geq 0$. For $\gamma = 0$ there are no learning effects from increasing the labour supply which means that λ is constant and equal to 1. However, for $\gamma > 0$, there are positive spillovers from employing an additional worker. Increasing the number of workers in the sector increases the quality of all workers in the same sector as well as in the other carbon-free energy sector. Further, $\delta \in \{0,1\}$ defines whether knowledge-spillovers are associated with alternative energy production only, or with backstop energy production as well. Note that in the former case we assume no spillover effects from the alternative energy sector to the backstop energy sector, whereas in the latter case we assume spillover effects between the two sectors. Let L_A and L_B denote the aggregate employment in the alternative and backstop sector respectively, and let a footnote *i* at a variable denote the firm specific variable. $\overline{L}_A$ is the BAU level of employment in the alternative energy sector, while by assumption $\overline{L}_B = 0$. Thus, we can specify the productivity-adjusted supplies of labour to single firms in the two sectors as follows:

(14) $\ell_{A,i} = L_{A,i}\lambda(L_A, \delta L_B) = L_{A,i}\left(\frac{L_A + \delta L_B}{\bar{L}_A}\right)^{\gamma}$

(15) $\ell_{B,i} = \begin{cases} L_{B,i} \, for \, \delta = 0 \\ L_{B,i}\lambda(L_A, L_B) = L_{B,i}\left(\frac{L_A + L_B}{\bar{L}_A}\right)^{\gamma} for \, \delta = 1 \end{cases}$

From (14) we see that employing an extra worker in a firm in the alternative energy industry increases the productivity-adjusted labour force for the whole sector in the following way:

(16) $\frac{\partial \ell_A}{\partial L_A} = \lambda + L_A \frac{\partial \lambda}{\partial L_A}$

The first term reflects the quality of the extra worker, whereas the second expresses the increased productivity of all other workers in the sector by employing the extra worker. For a single firm *i*, however, an increase in its own employment has the following impact on its productivity-adjusted labour force:

(17) $\frac{\partial \ell_{A,i}}{\partial L_{A,i}} = \lambda + L_{A,i} \frac{\partial \lambda}{\partial L_A} \approx \lambda$

The nature of the productivity growth is that spillovers are external to the firm, i.e., the competitive firm is so small that the latter term in (17) is approximately zero. This means that an individual firm ignores the latter term in (17). Thus, a firm in the alternative energy sector (or the backstop sector) considers λ as given.

The level of output from an alternative energy producer i is determined by:

(18) $\max p_A \phi_A K_{A,i}^{\theta_A} \ell_{A,i}^{(1-\theta_A)} - wL_{A,i}$

Using (17), we find the first order condition for profit maximisation, which shows that a single firm pays the marginal worker only his average product and employs labour according to:

$$(19)\ \ p_A \phi_A K_{A,i}^{\theta_A}(1-\theta_A)\ell_{A,i}^{-\theta_A} = \frac{w}{\lambda}$$

As the right hand side of (16) is larger than the similar term in (17), less labour is employed in the alternative energy sector than is optimal from the whole sector's point of view. The single firm does not take into account the spillover effects on other firms.

When there are spillovers from the alternative energy sector *only*, the corrective proportional subsidy, s^*, follows from the following equation:

$$(20)\ \ \frac{w}{\lambda}(1-s^*) = \frac{w}{\lambda + L_A \dfrac{\partial \lambda}{\partial L_A}}$$

thus,

$$(21)\ \ s^* = \frac{L_A \dfrac{\partial \lambda}{\partial L_A}}{\lambda + L_A \dfrac{\partial \lambda}{\partial L_A}}$$

In the CRTS model we found that the marginal productivity of labour in the alternative energy sector is determined by the fixed marginal productivity of labour in the backstop sector when the carbon constraint is binding and the backstop energy is produced. When there are positive spillover effects from learning in *both* the alternative energy and the backstop energy sector, the same result remains, and the production of alternative energy is actually the same as if there were no learning effects at all. To see this, consider the profit maximising condition for the existing energy aggregate, where the firm considers the spillovers as exogenous, see (11) and (17). In this case we have $\frac{\partial f(\ell_{A,i})}{\partial L_{A,i}} = \frac{\partial f(\ell_{A,i})}{\partial \ell_{A,i}} \lambda$, which implies:

(22) $$\frac{\partial f(\ell_{A,i})}{\partial \ell_{A,i}} = \frac{w}{\lambda p_E}$$

Also from profit maximisation in the backstop sector we find:

(23) $$\phi_B = \frac{w}{\lambda p_B}$$

As $p_B = p_E$ when the backstop energy is brought into the market, we see that $\frac{\partial f(\ell_{A,i})}{\partial \ell_{A,i}} = \phi_B$. Thus, the marginal product of quality-adjusted labour is the same as when there were no spillover effects from learning, and the production of alternative energy is identical. However, employment in the alternative energy sector differs in the two cases, as λ in general will differ from 1 when there are spillovers from both alternative energy and backstop energy.

With spillover effects emerging from learning in the alternative energy sector *only*, we have:

(24) $$\frac{\partial f(\ell_{A,i})}{\partial \ell_{A,i}} = \frac{w}{\lambda p_E} = \frac{w}{\lambda p_B} = \frac{\phi_B}{\lambda}$$

Thus, the marginal productivity of ℓ_A is higher than ϕ_B for $\lambda < 1$, i.e., $L_A < \overline{L}_A$, and less than ϕ_B for $\lambda > 1$, i.e., $L_A > \overline{L}_A$. As $\frac{\partial^2 f(\ell_A)}{\partial \ell_A^{\,2}} < 0$, an increase in the marginal product of ℓ_A means that ℓ_A has to be reduced. Thus, if employment in the alternative energy sector falls when the carbon constraint is introduced, less alternative energy is produced compared to the cases where there are either spillovers both in the alternative energy and in the backstop energy sectors, or in the case where spillovers are absent.

If L_A is subsidised, i.e., the alternative energy industry pays a wage equal to w(1-s), where $0 \leq s \leq 1$, the production of alternative energy will still be independent of whether there are spillover effects or not. However, replacing w by w(1-s) in equations (11), (22) and (24), we see that the marginal productivity of labour should be lower than without a subsidy. Thus, employment and production of alternative energy will increase in the subsidy rate in all three cases.

4. Numerical results

4.1. Calibration and scenarios

The elasticity parameter ρ in the CES production function is set equal to -1 implying an elasticity of demand for energy equal to roughly 0.5. The learning-by-doing parameter γ (see equations 14 and 15) is set equal to 0.25 when there are spillovers from labour supply. All other parameters are calibrated so that benchmark (BAU) equilibrium values are equal to one.[6] We then apply a carbon emission constraint equal to 75% of the BAU production of conventional energy (i.e., a = 0.75).

We run five different scenarios. For each scenario we assess climate policy simulations with different subsidy rates on alternative energy and an endogenous tax on conventional energy that exactly satisfies the carbon constraint. This provides a consistent basis for welfare analysis as we hold provision of the environmental public good constant. The scenarios are:

SPILLOVER – There are positive spillover effects from learning-by-doing in both the alternative and the backstop energy industry. The backstop cost is 10 per cent higher than the BAU energy price (p_E).

---

[6] Thus, the model is an illustrative one, not intended to replicate a particular economy.

CRTS – The same assumptions as for the spillover scenario apply, however, $\gamma = 0$ so there are no learning-by-doing effects.

LOWCOST - As the spillover scenario, however, the backstop cost is only 1 per cent higher than the BAU energy price.

NOBACKSTOP – As the spillover scenario, however, there are no backstop technologies, i.e., the backstop cost is infinite.

SPILL-EA – As the spillover scenario, however, there are no learning effects in the backstop sector and no spillovers from the alternative energy production to the backstop sector.

4.2. GDP effects

The percentage changes in GDP compared to BAU from introducing climate policies are shown in Figure 2. The costs are given for the different scenarios and different subsidy rates on alternative energy production. In both the SPILLOVER and LOWCOST scenarios there are positive GDP impacts from climate policies. The reason is that the introduction of the backstop energy improves aggregate labour productivity both within the backstop sector and for the production of alternative energy. This positive effect dominates the negative effect from the restriction and the induced higher price on conventional energy. A climate policy may therefore be a no-regret policy if the positive spillovers of the introduced backstop technology are sufficiently strong.[7] Also seen from Figure 2, the highest abatement costs are in the NOBACKSTOP scenario as expected. The outcomes from the CRTS and SPILL-EA scenarios are nearly identical. For no subsidies, the abatement costs are higher in SPILL-EA than in CRTS. The reason is that labour use falls in the alternative energy sector, and thus becomes less productive in SPILL-EA than in CRTS.

---

[7] Note that the positive GDP effects may be even higher if an optimal subsidy is introduced to correct for the positive externalities in backstop production.

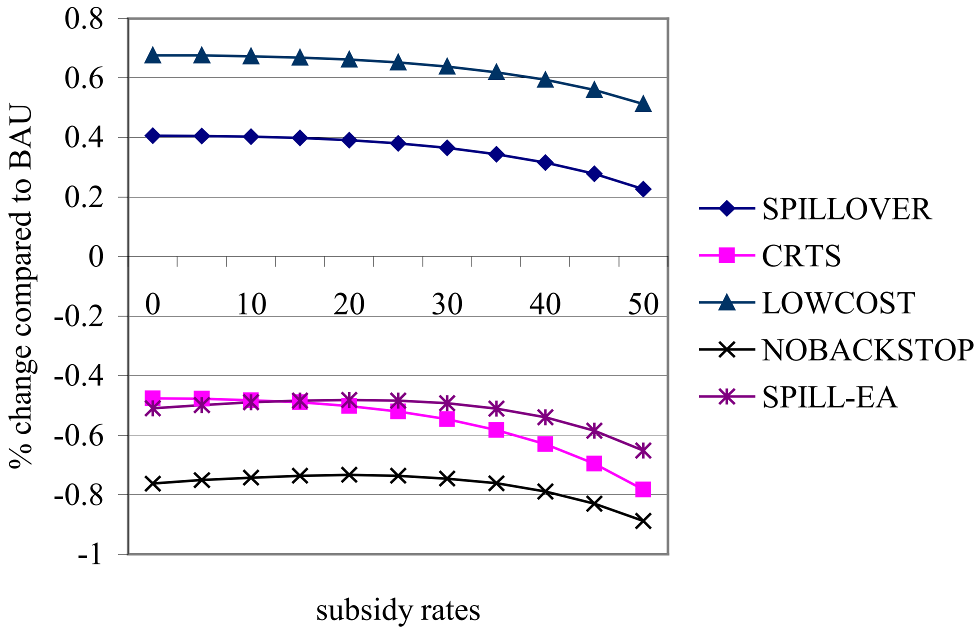


Figure 2: GDP effects for different subsidy rates

In all scenarios except NOBACKSTOP and SPILL-EA, GDP falls with a subsidy on alternative energy, implying that the optimal subsidy is equal to zero. In both NOBACKSTOP and SPILL-EA the optimal subsidy is 20%. When no backstop technology exists or there are no spillover effects in the backstop sector, the optimal policy is to correct for the positive externality in the alternative energy sector and then implement the necessary carbon tax. A subsidy on alternative energy may reduce the substitution towards other potential technologies, but this is socially optimal if other technologies do not create positive spillovers.

However, if a backstop technology also creates positive spillovers, the negative effects from ignoring these spillovers may be higher than the positive effects from correcting for the spillovers in the alternative energy sector. Thus, in a second best world where positive spillover effects from a potential technology are not corrected, there may actually be a loss from subsidising the alternative energy, and the subsidy should be set equal to zero.

4.3. Effects on alternative energy production

Figure 3 shows the impacts on the production of alternative energy under the different climate policies. The percentage change compared to BAU is shown. Consistent with the theory, the production of alternative energy increases in the subsidy rate in all scenarios. If no other technologies can be brought into the market, i.e., no backstop energy exists (the NOBACKSTOP scenario), the production of alternative energy will be higher than in BAU for all subsidy rates. In the other scenarios, however, a certain positive subsidy rate is necessary to prevent a decline in alternative energy production as a result of the climate policy.

The impacts on alternative energy production from introducing carbon restrictions are due to the sum of three different effects. As the price of conventional fuel increases due to the climate policy, there is a substitution from conventional fuels towards non-polluting energy, i.e., alternative energy and the backstop. However, as the existing energy aggregate becomes more expensive, i.e., as p_E increases, there is also a substitution from existing energy towards other input factors as labour and the backstop energy when this is available. Finally, if the gross domestic product falls as a result of the carbon policy (i.e., a positive abatement cost), the demand for all input factors fall. Note from Figure 2 that this effect actually increases the demand for input factors in the LOWCOST and SPILLOVER scenarios, as GDP increases. Among these three effects, the first increases the demand for alternative energy, the second effect reduces demand and the third effect is ambiguous.

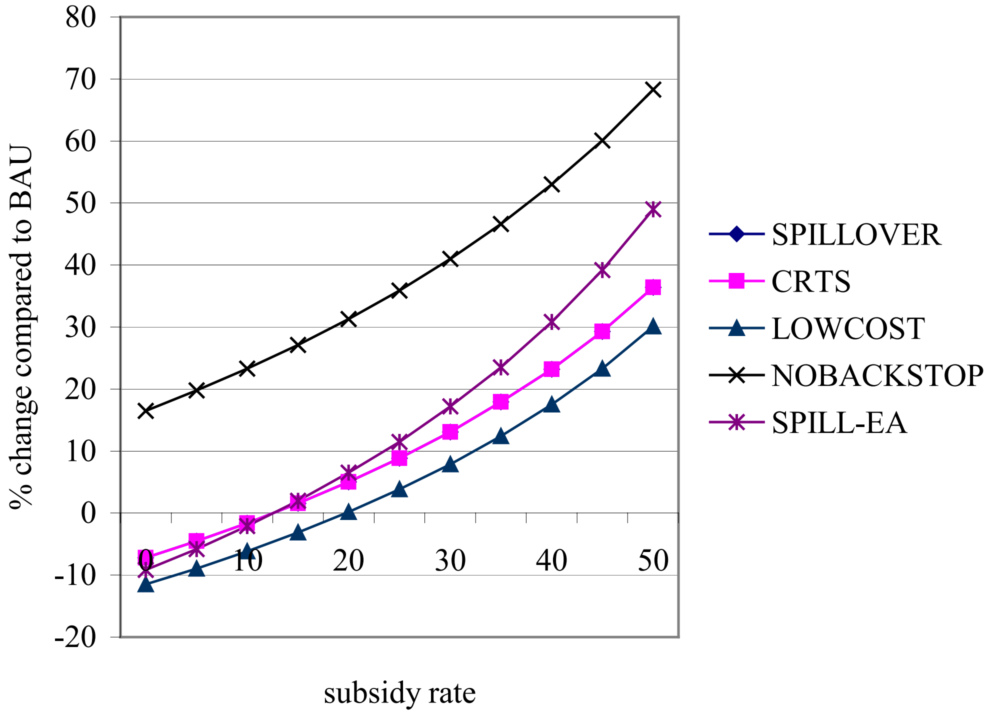


Figure 3: Alternative energy production for different subsidy rates

We see from Figure 3 that in the case of no subsidy, the largest fall in the demand for alternative energy is in the LOWCOST scenario. The reason is that the substitution from alternative and conventional energy towards the backstop is higher as the cost difference is not very high. As predicted by the theory, the production of alternative energy is the same in the SPILLOVER and the CRTS models. For no subsidies, less alternative energy is produced in the SPILL-EA scenario than in the BAU scenario, which also means that less labour is used. The theoretical analyses concluded that we should then have a lower production of alternative energy in SPILL-EA than in SPILLOVER and CRTS. This is confirmed with the reverse relationship as production rises above the BAU level. That is, the alternative energy production in SPILL-EA should then be higher than the corresponding production in SPILLOVER and CRTS.

4.4. Effects on backstop production

The effects of the climate policies on backstop production are shown in Figure 4, which gives the percentage of total energy supplied by the backstop. Backstop production falls in increasing subsidy rates to alternative energy as this reduces the substitution from the alternative energy towards the backstop. Not surprisingly, the backstop production is highest in the LOWCOST scenario, where it is produced at the lowest cost. It is also significantly higher in the SPILLOVER scenario than in the CRTS and SPILL-EA scenarios. This is mainly due to the learning effects, which lead to increased productivity and lower costs than in the two other scenarios. In addition, GDP is higher in the SPILLOVER scenario, which increases the demand for all input factors including energy. As the production of both conventional and alternative energy is equal in the SPILLOVER and the CRTS scenarios, the only way to increase energy supply in SPILLOVER compared to CRTS is to increase backstop production.

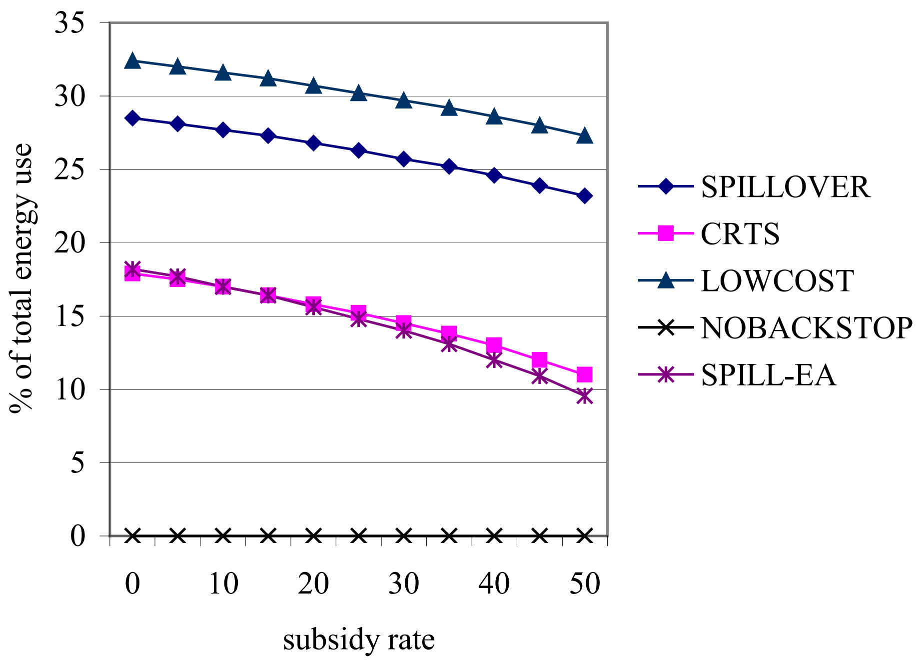


Figure 4: Backstop production for different subsidy rates

The backstop production with no subsidies is larger in SPILL-EA than in CRTS as the costs of producing alternative energy are higher (the productivity of labour is lower) in SPILL-EA, se above. However, when the subsidy rate gets high enough, alternative energy production increases compared to BAU, and the relationship between SPILL-EA and CRTS is reversed in the same way as for alternative energy.

4.5. Carbon taxes

The carbon taxes necessary to achieve the emission constraint are shown in Figure 5 for the different scenarios and different subsidy rates. It is measured in units of the BAU price on conventional energy. The carbon tax is highest in the NOBACKSTOP scenario where there is no possibility of replacing conventional energy with new energy technologies. The carbon tax is lowest when a backstop technology exists at a low cost, as this facilitates substitution from conventional energy towards non-polluting energy. Also, the carbon tax is higher in the CRTS scenario than in the SPILLOVER scenario because positive spillover effects reduce the costs of the backstop and therefore eases the transition from conventional to non-polluting energy.

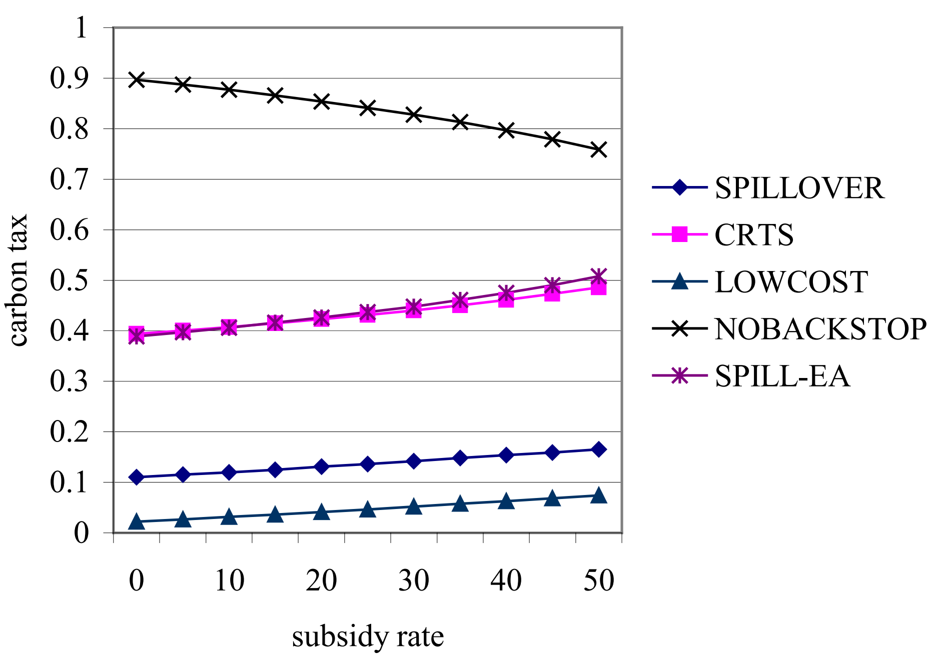


Figure 5: Carbon taxes for different subsidy rates

Both carbon taxes and alternative energy subsidies reduce carbon emissions when there is no backstop technology available. Therefore, the necessary carbon tax falls as the subsidy rate increases. However, the optimal policy mix is that which provides the lowest GDP loss (compare Figures 2 and 5). In scenarios where a backstop technology exists, introducing and then increasing a subsidy on alternative energy actually increases the requisite carbon tax. The reason is that the subsidy reduces the substitution from conventional and alternative energy towards backstop energy, and so an increasing carbon tax is necessary to meet the carbon constraint.

5. Concluding remarks

The lessons from these simulations are that subsidising an existing non-polluting technology may not be the right policy for two reasons. First, if the existing non-polluting energy production does not create any positive spillovers, a uniform carbon tax is the optimal policy. Second, even if the production of existing alternative energy creates positive spillovers, the optimal subsidy should not necessarily internalise all spillover effects and could actually be zero or even negative in a second best world. One reason is that the government may not know what technologies might enter the market after restrictions are placed on fossil fuel use. Energy production based on new technologies may also create positive spillovers. Subsidising existing alternative energy products may discriminate against new technologies when spillovers from new energy products are not rewarded. The argument is strengthened in rigid political systems where it is hard to remove old subsidies, as well as to introduce new ones. Thus, in a second best world with incomplete information about nascent technologies or with non-optimal policy rules, subsidising an existing technology amounts to "picking a winner".

We do not argue against subsidising positive externalities in general, even if our argument is also valid for other markets than energy. Energy and climate policy are special for several reasons. The production of energy is a dynamic process, and one important question is whether or not technologies used today may be used to a large extent in a few decades. Fossil fuels are the dominating energy sources in the current economic regime, and existing alternative energy sources may be viewed as complements to fossil fuels. The ultimate goal of the UN Framework Convention on Climate Change is to achieve "stabilisation of greenhouse-gas concentrations… at a level that would prevent dangerous anthropogenic interference with the climate system" (United Nations, 1992). This requires a large reduction of greenhouse gas emissions, and new energy technologies are probably necessary to meet this goal. Thus, if existing energy technologies are transitory, subsidies may delay the introduction of more sustainable energy technologies. This suggests that carbon taxes are a more neutral and efficient means of encouraging carbon-free energy than subsidies. Clear and consistent policy rules are important. Having a predictable carbon tax system may to a larger extent encourage the innovation of new, carbon-free energy.

One concrete example illustrates our point. In Norway there has been an ongoing national debate concerning the construction of two gas power plants. The plants, if constructed and operated at capacity, would increase Norwegian CO_2 emissions by about 6%, as power production is based on hydropower in Norway. However, proponents argue that the new electricity would replace electricity from coal power plants in Denmark and thus reduce overall European CO_2 emissions. If this is true, they would seem to be an environmental asset, however, the plants would not be economically profitable unless they are partly exempted from the Norwegian CO_2 tax. The majority in the Parliament is in favour of such exemptions.[8] The plan is to build the gas power plants using an existing technology, and exemptions from taxes amount to a subsidy. As has been shown in this paper, subsidies may be unjustified even if there exists external effects, spillovers that are doubtfully in the case of a mature technology like natural gas turbines. On a global basis, subsidy policies like this one may delay the introduction of new technologies such as hydrogen power plants or gas power plants with CO_2 injection, which are available but too expensive today, thereby raising the cost of assuring a safe level of greenhouse gases for future generations.

[8] The political dispute about this issue has been very intense in Norway, and the then Government actually resigned in early 2000 as the majority in the Parliament tried to force it to give tax exemptions to the producers of gas power.

References

Bovenberg, A. L. and S. Smulders (1995): Environmental quality and pollution-augmenting technological change in a two-sector endogenous growth model, *Journal of Public Economics*, 57: 369-391.

Chakravorty, U., J. Roumasset and K. Tse (1997): Endogenous Substitution among Energy Resources and Global Warming, *Journal of Political Economy*, 105(6): 1201-1234.

Goulder, L. H. and K. Mathai (2000): Optimal CO_2 Abatement in the Presence of Induced Technological Change, *Journal of Environmental Economics and Management*, 39: 1-38.

Goulder, L. H. and S. H. Schneider (1999): Induced technological change and the attractiveness of CO_2 abatement policies, *Resource and Energy Economics*, 21: 211-253.

Grübler, A. and S. Messner (1998): Technological change and the timing of mitigation measures, *Energy Economics*, 20: 495-512.

Gustavsson, P., P. Hansson and L. Lundberg (1999): Technology, resource endowments and international competitiveness, *European Economic Review*, 43, 1501-1530.

IPCC (1992): *Climate Change 1992 – The Supplementary Report to The IPCC Scientific Assessment*, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Johansen, L. (1965): *Public economics*, North-Holland, Amsterdam.

Kverndokk, S., L. Lindholt and K. E. Rosendahl (2000): Stabilisation of CO_2 concentrations: Mitigation scenarios using the Petro Model, *Environmental Economics and Policy Studies* **3** (2).

Schneider, S. H. and L. H. Goulder (1997): Achieving low-cost emissions targets, *Nature*, 389: 13-14 (4 September).

United Nations (1992): *UN Framework Convention on Climate Change*, United Nations, Climate Change Secretariat, Geneva.