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Promoting renewables and discouraging fossil energy consumption in the European Union

Abstract:
The European Union (EU) identified some positive and negative externalities related to energy production and consumption when adopting its Renewable Energy and Climate Change Package. Given these externalities, we derive the optimal combination of policy instruments. Thereafter, we explore the second-best outcome, given constraints on the use of some policy instruments, due to political considerations and international regulations. We show that the choice of policy instruments to promote renewable energy production (subsidies versus green certificates) affects the optimal level of energy consumption taxes. A second-best optimum for the EU cannot be achieved without a coordination of energy taxes and renewable energy policy instruments in each country, given the externalities addressed in this paper.

Keywords: climate policy, energy policy, green certificates, energy subsidies, energy taxes

JEL classification: D62, H21, H23, Q48

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1 Introduction

The purpose of this paper is to evaluate the cost effectiveness of the combined use of various energy and climate policy instruments, in the light of the recently adopted energy and climate policy of the European Union (EU). Our contribution to the literature on the design of policy instruments is to seek to identify the EU's underlying goals for its climate and energy policy, and take these goals as a point of departure for our evaluation of the optimal combination of policy instruments.

In December 2008 the EU Parliament agreed on a Renewable Energy and Climate Change Package aimed inter alia at achieving at least a 20% reduction in greenhouse gas emissions, and up to a 30% reduction in the event a comprehensive international climate agreement is established.[1] In addition the Package aims for a 20% share of renewables in overall EU energy consumption by 2020, see EU (2009a) and EU (2009b)).

In order to evaluate the cost effectiveness of policy instruments it is crucial to have well-defined policy goals (see Sorrell and Sijm, 2003). We find it reasonable to assume that the underlying goal for a combined energy and climate policy is to correct for externalities attached to consumption and production of energy.

When new policy instruments are introduced, the externalities they seek to address are not always well specified, even if their existence is the rationale for using the policy instruments. However, the EU identified some externalities from energy production and consumption when proposing the Renewable Energy and Climate Change Package (EU, 2008). Based on communications from the EU (see references below), we assume that the rationale for the EU's intervention in the energy markets is to correct for the following three externalities.

i) There is a negative externality related to emissions of greenhouse gases (GHG).

ii) There is a negative externality related to consumption of imported fossil fuels, as this increases dependency on fossil fuel imports.

iii) There is a positive externality related to the production of renewable energy.

One of the most pronounced environmental concerns today is global warming caused by emissions of greenhouse gases (externality *i.*). The EU has on several occasions promoted the need for reducing emissions of GHG.

In a press release from the EU (EU, 2008), it is argued that setting a target for the share of renewables in overall energy consumption helps

[1] The target for emissions reduction is not an exclusively domestic reduction target, as the Package allows for some limited trade in emissions credits with third countries.

to decrease reliance on imported fossil fuels, which makes energy supply more certain for European citizens. This implies that the EU attaches a negative externality to dependence on imported fossil fuels, leading us to externality *ii*) above. Measures to decrease dependence on imported fossil fuels can, inter alia, be motivated by unstable political situations in large exporting countries. See Löschel et al. (2010) for a discussion about energy security.

Another argument from the EU, supporting the renewable energy target, is an anticipated subsequent boost for high-tech industries, producing new economic and employment opportunities (EU, 2008, 2009b (3)). These arguments suggest that the EU attaches positive externalities to the production of renewable energy, which leads us to specification *iii*) above.

Although there may be important social welfare benefits from net increases in employment that may result from increased production of renewables, stimulating employment through policies to increase renewable energy production is probably not the most cost-effective way of preventing unemployment. Furthermore, although stimulating production in industries can be welfare improving if there are technological spillovers that are not taken into account by the producers (see Stoneman and Vickers, 1988; Pizer and Popp, 2008), there may be more efficient ways to make the industries internalize these externalities than by stimulating production of renewable energy. (The relationship between technological change and environmental policy instruments has been widely discussed in the literature; see, e.g., Jaffe et al., 2002; Kverndokk and Rosendahl, 2007; Fischer and Newell, 2008.) However, in this study, we do not assess the nature of (or the rationale for) the positive externality the EU associates with renewable energy production but merely take it as a premise for our study.[2] In the concluding remarks we discuss the outcome in the absence of such an externality (externality *iii*).

As a starting point, we first derive the optimal combinations of policy instruments given the externalities defined above, with no constraints on the choice of policy instruments. However, due to international regulations and/or political considerations (see Bennear and Stavins, 2007), it is reasonable to assume that a regulator faces constraints on the use of policy instruments. The constraints on the policy instruments we consider are restrictions on the use of import tariffs, because of international trade regulations, and restrictions on the use of subsidies to fossil fuel production, because of political considerations.

We relate our findings to the current use of policy instruments in the

[2] Böhringer and Rosendahl (2010) show the inefficiency of introducing a target for green energy consumption when the policy aim is only to limit CO_2 emissions.

EU. In particular, as renewable energy is promoted by subsidies in some member states and by a green certificate market in other member states, we find it of interest to compare the features of these two instruments. (For analysis of green certificate markets, see Amundsen and Mortensen, 2001; Morthorst, 2003; Bertoldi and Huld, 2006.)

We show that as long as there are no constraints on the use of subsidies on energy production, the regulator can achieve the first-best outcome, even if there is a constraint on the use of import tariffs. If there are constraints on the use of both import tariffs and subsidies on domestic fossil energy production, the regulator cannot ensure a first-best domestic production of fossil fuels. The second-best optimal outcome can be achieved by a combination of a CO_2 tax, an energy consumption tax and a renewable energy production subsidy. The second-best renewable energy production subsidy deviates from the Pigovian level as it also captures the negative externality from fossil fuel imports. Furthermore, we show that the introduction of a green certificate market to promote the production of renewable energy can ensure the second-best optimal outcome but demands a lower energy consumption tax than if renewable energy is promoted by a subsidy. Hence, the Renewable Energy and Climate Change Package proposed by the EU cannot ensure an efficient outcome if renewable energy is regulated by subsidies in some regions and by the use of green energy certificates in other regions, unless the energy consumption tax is adjusted accordingly.

In the next section we present the model. In section 3, we derive an optimal combination of policy instruments when both import tariffs and general production subsidies are allowed. In section 4, we derive the optimal combination of policy instruments when import tariffs are banned but general production subsidies are allowed. Given a ban on both import tariffs and subsidies to domestic fossil energy production, we derive the second-best combination of taxes and renewable energy subsidies in section 5 and the second-best combination of taxes and green energy certificate obligations in section 6. In the concluding remarks in the last section, we discuss the discrepancy between our results regarding optimal policy instruments and (some of) the current use of policy instruments in the EU.

2 The model

We consider climate and energy policy in one country or a group of countries, like the EU, seeking to maximize joint welfare from consuming final energy and producing energy sources. We henceforth use the single form "country" also for the case where a group of countries is subject to the same regulatory regime. To simplify we consider only two types of energy; fossil and renewable (green).[3] The country produces both fossil and renewable energy. We do not consider any international trade in renewable energy. Hence, domestic production of renewable energy equals domestic consumption of renewable energy. This assumption can be justified by constraints on transmission and distribution of electricity, which is the main source for transport of renewable energy.[4] However, fossil fuels are traded on the international market.

For consumers, we assume that both types of energy are perfect substitutes. This is a reasonable assumption if we only consider electricity where consumers cannot separate between electricity produced by renewable or by fossil energy sources. Assuming perfect substitution when we also consider other kinds of energy use is obviously a simplification, but different kinds of energy sources become more competitive over time, for instance through the use of biofuels and electricity as a substitute to petrol in the transport sector.

The consumption of energy (e) is the sum of consumption of fossil (b) and renewable energy (x), measured in the same energy units:

$$e = b + x.$$

Let y denote domestic production of fossil energy. We assume throughout the paper that the country is a net importer of energy. The consumption gap for energy is covered by net imports of fossil energy, z:

$$z = e - x - y. \tag{1}$$

We assume that the country we consider is a price taker in the international fossil energy market. Hence, we ignore any strategic behavior in the energy market in order to influence energy prices.[5]

We consider the three externalities described in the introduction.

We assume that the country participates in an international climate agreement with quantified emissions targets, with possibilities for permit trade, such that the cost of emissions equals the international permit price. Other specifications of the (externality) cost of emissions would

[3] By considering only one type of fossil fuel we ignore any impact on the distribution of consumption across various source of fossil energy. However, this simplification does not have any impact on the main conclusion of the paper.

[4] This simplification is a reasonable description of the situation in the EU. The net export of electricity is close to zero. The gross import and export amounts to approximately 10% of electricity production by the EU (see Eurostat (2008)). Biomass imports in EU27 are also small. In 2008, net imports as share of total primary biomass supply amounted to 2.4% and 4.5% of total imports (IEA, 2009).

[5] The design of a carbon tax when the terms of trade effects are accounted for typically comprises an optimal tariff term (see Golombek et al. (1995) and Hoel (1996)).

not influence the conclusions of this paper (see discussion in the concluding remarks).

The country must hold permits corresponding to the emissions resulting from fossil energy consumption, b:

$$b = y + z. \tag{2}$$

Let q denote the international price on permits per unit fossil energy.

Let $\sigma(z)$ denote the negative externality of fossil energy imports, $\sigma' > 0$.. Let $\varphi(x)$ define the positive externality associated with the production of renewable energy, $\varphi'(x) > 0$.

Let $B(e)$ denote the benefit from consuming energy, and $c(x)$ and $f(y)$ domestic cost functions for producing renewable and fossil energy, respectively. We make the standard assumption about positive and decreasing marginal benefit of consumption and positive and increasing marginal cost of production; that is, $B' > 0$, $B'' < 0\, c' > 0, c'' > 0, f' > 0$ and $f'' > 0$.

2.1 Welfare optimum

We first derive the optimal use and production of the two types of energy, given the externalities i)–iii). The welfare associated with energy consumption and production is:

$$\Omega = B(e) - c(x) - f(y) - P_z z + q(\bar{b} - b) - \sigma(z) + \varphi(x), \tag{3}$$

where $\bar{b}$ is the initial endowment of permits set by the international climate agreement and P_z is the international price on imported fossil energy. Inserting from (1) and (2), and maximizing (3) w.r.t. e, x and y, yields the following first-order conditions:

$$B' = P_z + q + \sigma', \tag{4}$$

$$c' = P_z + q + \sigma' + \varphi', \tag{5}$$

$$f' = P_z + \sigma'. \tag{6}$$

Let $x^*, y^*, e^*, z^*$and b^* denote the solutions to (1), (2) and (4)-(6).

As we consider a net importer of fossil energy and a given world market price on energy, a marginal increase in energy consumption leads to a corresponding increase in fossil fuel imports. Equation (4) tells us that the marginal benefit of energy consumption should equal the international price on fossil fuel plus the cost of emission permits to cover the corresponding emissions of CO_2, q, and the negative externality of fossil fuel import, σ'. Equation (5) states that marginal production cost of renewable energy should equal the marginal benefit of replacing one unit fossil fuel import by the domestically produced renewable energy ($P_z + q + \sigma'$), plus the positive externality associated with renewable energy production, φ'. Domestic production of fossil fuels also saves net import costs and reduce the fossil fuel import dependency, but does not reduce the emissions of CO_2. Hence, the marginal benefit of fossil fuel production equals $P_z + \sigma'$(eq.(6)).

3 Market implementation

In this section, we show how the regulator, by the use of three policy instruments, can induce the domestic competitive agents to internalize the three externalities and thereby achieve the welfare optimum. The regulator introduces CO_2 taxes, t, on fossil energy consumption, an import tariff, m, on imported energy, and a subsidy, r, on renewable energy production. (The domestic regulation of CO_2 emissions could alternatively be ensured by tradable permits; see below.)

The domestic consumer price on imported fossil energy, z, equals the international price plus tariffs and taxes levied on fossil fuel import. Since all kinds of energy are assumed to be perfect substitutes, the consumer price on energy cannot differ between the various types, if all types of energy are to be consumed. This implies that the consumer price on all types of energy (p) equals:

$$p = P_z + t + m. \tag{7}$$

The producer price on a domestically produced energy source i must in equilibrium equal the consumer price less any net taxes (taxes minus subsidies) levied on the energy source i. Hence, the producer price on renewable energy, P_x, equals the consumer price plus the direct subsidy (r) to renewable energy production:

$$P_x = P_z + t + m + r. \tag{8}$$

Consumers also pay a CO_2 tax on domestically produced fossil energy. Consequently, the producer price, P_y, is given by:

$$P_y = P_z + m. \tag{9}$$

Consumers maximize their welfare:

$$W = B(e) - pe. \tag{10}$$

The renewable and fossil energy producers' profits, denoted π_x and π_y are given by, respectively:

$$\pi_x = P_x x - c(x), \tag{11}$$

$$\pi_y = P_y y - f(y). \tag{12}$$

Inserting from (7)–(9) into (10)–(12) and maximizing with respect to e, x and y, respectively, we find the following first-order conditions:

$$B' = P_z + t + m, \tag{13}$$

$$c' = P_z + t + m + r, \tag{14}$$

$$f' = P_z + m. \tag{15}$$

Proposition 1 *Given a positive externality associated with production of renewable energy and negative externalities associated with fossil fuel imports and emissions of greenhouse gases, the first-best outcome can be achieved by the introduction of an import tax, a renewable energy subsidy and a* CO_2 *tax.*

Proof. We see from comparing (4)–(6) with (13)–(15) that first-best is achieved for $t = t^* = q, m = m^* = \sigma'(z^*)$ and $r = r^* = \varphi'(x^*)$. ■

We refer to $t^*, m^*$and r^* as the Pigovian taxes (subsidy) on CO_2 emissions, fossil fuel import and renewable energy production, respectively. So far, we have considered the use of domestic CO_2 taxes to control CO_2 emissions. As we have assumed an international climate agreement with quantified emission targets, this implies that the regulator must trade permits on the international permit market in order to ensure compliance. An identical outcome would be achieved if all domestic emitters are obligated to hold permits corresponding to their emissions and are allowed to trade permits on the international permit market, as $t^* = q$.

The use of an import tariff, m, will most likely provoke complaints to the World Trade Organization, as it violates the Organization's rules. In the next section we derive the regulator's optimal taxation schemes, given a ban on import tariffs.

4 Optimal tax scheme under a ban on import tariffs

If the regulator is prevented from using import tariffs, the regulator can, in addition to a CO_2 tax and a renewable energy subsidy, introduce a general subsidy on all domestic energy production, s, and a tax, T, on energy consumption. The consumer price on energy is thus given by:

$$p = P_z + t + T. \tag{16}$$

The producer price on renewable and fossil energy is given by:

$$P_x = P_z + t + s + r, \tag{17a}$$

$$P_y = P_z + s. \tag{18}$$

Inserting for the price functions (16)–(18) in (10)–(12) and maximizing with respect to e, x and y, we find that the first-order conditions correspond to (13)–(15) for m in (13) replaced by T and m in (14)–(15) replaced by s.

Proposition 2 *By substituting an optimal import tariff with the combined use of a general tax on energy consumption and a domestic general energy production subsidy, the regulator achieves the first-best outcome.*

Proof. We see from comparing (4) with (13), where m is replaced by T, and comparing (5)–(6) with (13)–(15), where m is replaced by s, that first-best is achieved for $t = t^* = q, T = T^* = m^* = \sigma'(z^*), s = s^* = m^* = \sigma'(z^*)$ and $r = r^* = \varphi'(x^*)$. ■

The regulator mimics the outcome of import tariffs by the use of production subsidies and consumption taxes, where both the subsidy and the tax correspond to an optimal tariff. The optimal tariff increases both the consumer price on energy and the domestic producer price on both types of energy by m^*. This price increase is now replaced by a corresponding tax T^* on energy consumption and a corresponding subsidy s^*on productions of both types of energy, such that both the producer prices and the consumer prices remain the same as under an optimal tariff. The constraint on the use of import tariffs forces the regulator to use four policy instruments (t^*, T^*, s^*,m^*) to ensures the fulfillment of the three first-order conditions for the first-best outcome, (4)–(6).

Hence, although there is no externality directly linked to the consumption of energy in general, the optimal outcome can be achieved by the inclusion of a general tax on energy consumption. Furthermore, a general subsidy on domestic energy production is also a part of the optimal tax scheme. The coal industry is subsidized in several European countries, and this policy has been heavily criticized (see, e.g. OECD, 2005).[6] We have shown that when increased dependence of imported fossil fuels is a negative externality associated with fossil fuel import, and there is a ban on import taxes, it is welfare improving to stimulate domestic production of fossil fuels.

With increased environmental concern among the population it can be harder to win acceptance for a policy that implies a subsidy on fossil energy production. In the next section we consider the optimal outcome given that the regulator can implement neither import tariffs nor subsidies on nonrenewable energy production.

5 Restrictions on the use of import taxes and general energy subsidies—Second-best optimal

If the regulator is prevented from using import tariffs, and there is a (political) constraint on implementing subsidies on nonrenewable energy production, the regulator cannot influence the production of y. Given $s = 0$, we see from (18) that domestic production of fossil fuels is determined by the (exogenous) international producer price on fossil fuels (P_z):

$$y(P_z) = \overline{y}. \tag{19}$$

Under this constraint, the regulator cannot ensure the first-best production of fossil fuels. The second-best outcome of the welfare optimization problem is found by maximizing (3) subject to (19):

$$B' = P_z + q + \sigma', \tag{20}$$

$$c' = P_z + q + \sigma' + \varphi'. \tag{21}$$

Let $x^{**}, e^{**}, z^{**}, \overline{y}$ and b^{**} denote the solutions to (2), (1) and (19)–(21). Note that for a constant marginal cost of all of the externalities ($\sigma''(z) = 0$ and $\varphi''(x) = 0$), x^{**} and $e^{**}$are equal to the first-best outcomes.

5.1 Implementing the second best

In this section we consider a tax scheme to implement the second-best solution. We consider tax on energy consumption, T, a subsidy on re-

[6]Subsidies to energy producers usually take the form of grants, loans and tax exemptions (see OECD, 2005).

newable energy production (r), and a CO_2 tax (t), but no subsidy on energy production or import tariff. The consumer price on energy is given by (16).The producer price on renewable energy is given by:

$$P_x = P_z + t + r. \tag{22}$$

The production of fossil energy is given by (19). Inserting for the price functions (16) and (22) in (10) and (11), and maximizing with respect to e and x, we find the following first-order conditions:

$$B' = P_z + t + T, \tag{23}$$

$$c' = P_z + t + r. \tag{24}$$

The equations define $e(t, T)$ and $x(t, r)$. By comparing (23)–(24) with (20)–(21) we derive the following proposition:

Proposition 3 *Consider a situation where there are restrictions on the use of import taxes and fossil energy production subsidies. The regulator can achieve the second-best optimal outcome by a tax on energy consumption, a CO_2 tax, and a renewable energy production subsidy. The second-best renewable energy production subsidy exceeds the positive externality of renewable energy production.*

Proof. Consider the following taxes: $T = T^{**} = \sigma'(z^{**}), t = t^{**} = q, r = r^{**} = \sigma'(z^{**}) + \varphi'(x^{**})$. We see from (23)–(24) and (4)–(6) that this tax structure leads to the second-best optimal solution and $r^{**} > \varphi'(x^{**})$. ■

In the absence of import tariffs and general energy production subsidies, the second-best optimal renewable energy subsidy corresponds to the sum of the externalities associated with renewable energy production and fossil fuel import. Increasing r above $\varphi'(x^{**})$ leads to higher production of renewable energy, and the import of fossil fuel falls. Hence, the renewable energy production subsidy helps to correct for the negative externality of fossil fuel imports, in addition to correcting for the positive externality of renewable energy production.

In EU countries' current policies one can observe taxes on energy consumption (in addition to CO_2 taxes) and subsidies on renewable energy productions, for instance, feed-in tariffs. As we have shown here, it can be optimal to set a feed-in tariff above the external benefit from renewable energy production if countries are restricted from using import tariffs and subsidies on fossil energy production.

So far we have assumed that the regulator uses a subsidy to promote renewable energy production. Another approach currently in use

to promote renewable energy is the green certificate system. The system requires that consumers of energy must purchase green certificates corresponding to a share of their total consumption. The producers of renewable energy have the right to issue green certificates. The market for green certificates determines the price for certificates. This system does not imply any governmental spending as the subsidy (green certificate value) is financed by the energy consumers. The system ensures that the total share of renewable energy of total energy consumption equals the level set by the regulator. In the next section we consider the situation where the renewable subsidies are replaced by a green certificate system
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6 Green certificate market combined with a CO_2 tax.

Let α be the share of renewable energy in the overall consumption:

$$\alpha = \frac{x}{e} = \frac{x}{x+y+z}, \qquad 0 < \alpha < 1. \tag{25}$$

The consumers of energy are obliged to purchase α green certificates for each unit energy consumed, and producers gain the right to sell one green certificate for each unit of renewable energy they produce. Let β denote the unit price on certificates. We assume that the green certificate system is additional to the CO_2 tax and a general energy consumption tax, T. The consumer price on energy is:

$$p = P_z + t + T + \beta\alpha. \tag{26}$$

The producer price on energy source i equals the consumer price less the green certificate cost and other net taxes on energy source i, plus the income from generating certificates for i=x:[7]

$$P_x = P_z + t + \beta, \tag{27}$$

$$P_y = P_z. \tag{28}$$

Consumers' welfare function is:

$$W = B(e) - (P_z + t + T + \beta\alpha)e. \tag{29}$$

The renewable producers' profit function is given by:

[7] $P_x = p - \beta a + \beta = P_z + t + \beta$. As in the previous section, domestic production of fossil fuels is determined by the international producer price on fossil fuels (see (19)).

$$\pi_x = (P_z + t + \beta)x - c(x). \tag{30}$$

The production of fossil energy is given by (19). Maximizing (29) with respect to e, and maximizing (30) with respect to x, we find the following first-order conditions:

$$B' = P_z + t + T + \beta\alpha, \tag{31}$$

$$c' = P_z + t + \beta. \tag{32}$$

From (31) we can write the demand for energy as a function of the price on energy and of the green certificates expenditure per unit energy consumption, $e(P_z + t + T + \beta\alpha)$. From (32), we find the supply of renewable energy as a function of the green certificate price and the producer price for energy, $x(P_z + t + \beta)$. The market clearing condition for green certificates is therefore:

$$x(P_z + t + \beta) = \alpha e(P_z + t + T + \beta\alpha). \tag{33}$$

From (33) we find the market clearance price on green certificates as a function of t, T and α, that is $\beta(t, T, \alpha)$.

Proposition 4 *Consider a situation where there are restrictions on the use of import taxes and fossil energy production subsidies. The regulator can achieve the second-best outcome by a green certificate system combined with a CO_2 tax and a tax on energy consumption. Replacing a renewable energy subsidy with a green certificate system induces a lower optimal tax on energy consumption.*

Proof. Let the CO_2 tax be given by the Pigovian level t^*. As $\beta(t^*, T, \alpha)$ is found from (33), the regulator has two policy instruments (T and α) to regulate the two variables e and x ((31)–(32)). Second-best optimality implies that the right-hand side of (31)–(32) must equal the right-hand side of (20)–(21). The second-best optimal outcome is characterized by $t = t^* = q$, $\beta = \sigma'(z^{**}) + \varphi'(x^{**})$ and $T = T^g = [1 - a^{**}]\,\sigma'(z^{**}) - \varphi'(x^{**})$, where $a^{**} = \frac{x^{**}}{e^{**}}$. Hence, $T^g < T^{**}$. ■

Introducing a green certificate market in addition to a CO_2 tax and a tax on energy consumption can achieve the second-best allocation of energy production and consumption, given the externalities *i*) - *iii*). However, replacing a subsidy on renewable energy production with a green certificate system demands a downward adjustment of the energy consumption tax. We cannot rule out the possibility that the second-best optimal tax on energy consumption is negative. We see from the proof of proposition 4 that $T^g < 0$ for $[1 - a^{**}]\,\sigma'(z^{**}) < \varphi'(x^{**})$. In that case, the regulator must subsidize the use of energy to achieve second-best optimal allocation. A green certificate system implies a higher cost of energy consumption. Although the *share* of renewables is set equal to second-best ($a^{**} = \frac{x^{**}}{e^{**}}$), the level of consumption may become too low compared to second-best (e^{**}) for $T^g \geq 0$. In that case the consumption of energy must be subsidized to achieve the second-best level. As pointed out in Aune et al. (2008), a green certificates market is not an efficient instrument for correcting for externalities. However, we have shown that a green certificate market can be designed to achieve (second-best) efficiency if it is *combined* with optimal design of energy taxes. But it is important to note that the second-best outcome also demands that the share of renewables is set at the second-best optimal level. Hence, the regulator must not only have knowledge about the externalities of energy consumption and production, as in section 5.1, but also about the optimal share of renewables.

Another important lesson is that the combined use of policy instruments should be coordinated across all consumers. The optimal tax on energy in case of a green certificate system differs from the optimal tax in the case of renewable energy subsidies. This leads to the following corollary:

Corollary 5 *If all consumers face the same price on energy consumption and CO_2 emissions, an optimal outcome cannot be ensured if renewable energy is regulated by subsidies in some regions and by the use of green certificates in other regions.*

The EU seeks to harmonize energy consumption taxes (EU, 2003). Our results show that a harmonization of energy consumption taxes demands coordination of renewable energy policies across EU members to achieve an optimal outcome for the EU.

7 Concluding remarks

In the introduction we argued that in order to discuss the cost effectiveness of the use of policy instruments, it is crucial to have a well-defined policy objective. In this study we assumed that the regulator wanted to correct for three externalities; a positive externality from production of renewable energy, a negative externality from fossil fuel import, and a negative externality from fossil fuel consumption (CO_2-emissions). These are all externalities from energy production and consumption that are explicitly addressed by the European Commission in its Renewable Energy and Climate Change Package. Given these externalities, it is optimal to subsidize domestic production of fossil fuels in a setting where import tariffs are banned. However, this does not mean that countries that, for instance, subsidize their coal production, necessarily implement a cost-effective policy. The climate and energy policies in many EU countries are typically characterized by tax exemption, reduced tax rates or subsidized electricity contracts for specific groups. Differentiating taxes and subsidies across producers and across consumers (of one type of fuel) is not part of an cost-effective climate and energy policy, given the externalities we have considered in this paper.

We have assumed that the regulated country (group of countries) participates in an international climate agreement with an international price on emissions permits. If this is not the case, the tax on emissions should correspond to the external cost of CO_2 emissions, whatever that is perceived to be. All our conclusions regarding second-best taxation of emissions relative to the first-best will still hold.

The EU's Renewable Energy and Climate Change Package contains several examples of inefficient use of policy instruments and inefficient regulations. For instance, the target for the emissions reductions in 2020 is partly achieved by emissions reductions from sources covered by the EU's emission trading scheme (EU-ETS) and partly by differentiated national targets for sources not covered by EU-ETS (EU, 2009a, 2009c). However, emission reductions can only be achieved in a cost-effective manner if there are no constraints on emissions trading across sectors and countries. Since the EU-ETS directive sets restrictions on the use of emissions trading for sectors covered by the EU-ETS, cost effectiveness will not be achieved (EU, 2009c (32)).

Nationally differentiated renewables targets are another example of inefficiency. To achieve the target of a 20% share of renewables in the EU's total energy consumption, the Council has adopted mandatory differentiated national targets for each of the member states (EU, 2009b, appendix I). Obviously, without instruments to distribute the production of renewable energy across countries cost-effectively, differentiated national targets increase the cost of fulfilling the overall renewable target (SEC, 2008).

This paper has pointed to yet another potential source for inefficiency. We have shown that the choice of policy instruments to promote renewable energy production (subsidies versus green certificates) affects the optimal level of general energy taxes. So far, this is not taken into account in the EU as the EU member states are free to choose domestic instruments to promote renewable energy production independently of their energy consumption taxation. Second-best optimum for the EU cannot be achieved without a coordination of energy taxes and renewable energy policy instruments in each country, given the externalities addressed in this paper.

We have taken as a starting point that the EU attaches a positive externality to the production of renewable energy. This was based on the EU's argument that the renewable directive inter alia could give a boost to high-tech industries, new economic opportunities and jobs. We argued in the introduction that these consequences could probably better be addressed by other policy instruments, more directly aimed at supporting high-tech industries or employment. If that is done, the remaining positive externality from renewable energy production would perhaps be of minor value. However, domestically produced renewable energy is a substitute for imported fossil energy, and as long as there is a negative externality from fossil import, it is second-best optimal to stimulate renewable energy production if there are restrictions on the use of import taxes and fossil energy subsidies. This can be seen from the proof of proposition 3, as $r^{**} > 0$ for $\varphi'(x^{**}) = 0$.

References

[1] Amundsen, E. S. and J. B. Mortensen (2001). The Danish Green Certificate System: some simple analytical results. Energy Economics 23, 489–509.

[2] Aune, F. R., R. Golombek, S. A. C. Kittelsen and K. E. Rosendahl (2008). Liberalizing European Energy Markets. An Economic Analysis. Cheltenham, UK, Edward Elgar Publishing.

[3] Bennear, L. and R. Stavins (2007). Second-best theory and the use of multiple policy instruments. Environmental and Resource Economics 37, 111–129.

[4] Bertoldi, P. and T. Huld (2006). Tradable certificates for renewable electricity and energy savings. Energy Policy 34, 212–222.

[5] Böhringer, C and K. E. Rosendahl (2010). Green serves the dirtiest: On the interaction between black and green quotas, accepted manuscript, Journal of Regulatory Economics.

[6] EU (2003). Council Directive 2003/96/EC of 27 October 2003, Official Journal of the European Union.

[7] EU (2008). "MEMO/08/33, date 23 January", EUROPA—press releases.

[8] EU (2009a). DECISION No 406/2009/EC of the European Parliament and of the Council, Official Journal of the European Union.

[9] EU (2009b). DIRECTIVE 2009/28/EC of the European Parliament and of the Council, Official Journal of the European Union.

[10] EU (2009c). DIRECTIVE 2009/29/EC of the European Parliament and of the Council, Official Journal of the European Union.

[11] Eurostat (2008). Energy—Yearly Statistics 2006, European Commission.

[12] Fischer, C. and R. G. Newell (2008). Environmental and technology policies for climate mitigation. Journal of Environmental Economics and Management 55 (2): 142–162.

[13] Golombek, R., C. Hagem and M. Hoel (1995). Efficient incomplete international climate agreements. Resource and Energy Economics 17 (1): 25–46.

[14] Hoel, M. (1996). Should a carbon tax be differentiated across sectors? Journal of Public Economics 59 (1): 17–32.

[15] IEA (2009). Extended Energy Balances edition 2009 with 2008 data, International Energy Agency.

[16] Jaffe, A., R. Newell and R. Stavins (2002). Environmental policy and technological change. Environmental and Resource Economics 22(1): 41–70.

[17] Kverndokk, S. and K. E. Rosendahl (2007). Climate policies and learning by doing: Impacts and timing of technology subsidies. Resource and Energy Economics 29(1): 58–82.

[18] Löschel, A., U. Moslener and D. T. G. Rübbelke (2010), Indicators of energy security in industrialized countries. Energy Policy 38 (4): 1665–1671.

[19] Morthorst, P. E. (2003). Green certificates and emission trading. Energy Policy 31(1): 1–2.

[20] OECD (2005). Environmentally Harmful Subsidies. Challenges for Reform, OECD Publishing.

[21] Pizer, W. A. and D. Popp (2008). Endogenizing technological change: Matching empirical evidence to modeling needs. Energy Economics 30(6): 2754–2770.

[22] SEC (2008). "Annex to the impact assessment." Commission Staff Working Document, SEC (2008) 85, Commission of the European Communities.

[23] Sorrell, S. and J. Sijm (2003). Carbon trading in the policy mix. Oxford Review of Economic Policy 19(3): 420–437.

[24] Stoneman, P. and J. Vickers (1988). The assessment: The economics of technology policy. Oxford Review of Economic Policy 4(4): i–xvi.