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Abstract

There are conflicting views on how to handle permits for greenhouse gases in cost–benefit analysis. This paper aims at clarifying within a simple general equilibrium model how to treat different kinds of tradable permits in economic evaluations of projects. Within a framework that reminds of the EU Emissions Trading System (EU ETS), the paper looks at cost–benefit rules for a small project providing a public good, interpreted as a shortcut for infrastructure, using a fossil fuel and a renewable as inputs. In addition, it illustrates the Samuelson condition for the optimal provision of the public good, discusses briefly how to assess the EU permit system for sectors not covered under the EU ETS, as well as taxes and permits used to combat acid rain, and provides an illustration of the magnitude of the bias incurred if permits are valued at the marginal damage cost. The paper also introduces electricity ("green") certificates, a cousin to tradable permits, as well as well as energy savings ("white") certificates. Finally, a cap on the output of a commodity is considered.

Keywords: Cost–benefit analysis; greenhouse gases; emissions trading; tradable permits; general equilibrium; Samuelson condition; EU ETS; non-ETS; acid rain; electricity certificates; renewable portfolio standards; energy savings certificates; output cap.

JEL-codes: H21; H23; H41; H43; I 30; L13.

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1 Introduction

According to the International Carbon Action Partnership (2015) there are 17 carbon emissions trading systems in force across four continents, covering 35 countries, 12 states or provinces, and seven cities; refer to International Carbon Action Partnership (2016) for planned and operating emissions trading systems around the world. The largest one is the European Unions EU Emissions Trading System (EU ETS) launched in 2005. It covers the European Economic Area (EEA), i.e., the 28 EU Member States plus Iceland, Liechtenstein, and Norway. In 2013, the EU ETS covered more than 12,000 power stations and industrial plants, as well as 1,300 airlines (since 2012).[1] Within limits, they can also buy credits from certain types of approved emission-saving projects around the world. More and more of the permits are auctioned rather than being given to companies based on historical emissions (grandfathering). Two auction platforms are in place. The European Energy Exchange (EEX) in Leipzig is the common platform for the large majority of countries participating in the EU ETS. The second auction platform is ICE Futures Europe (ICE) in London, which acts as the United Kingdom's platform. At least half of revenues from auctioning permits to power stations and industrial plants, and all of the revenues from auctioning permits to the aviation sector, should be used to combat climate change. However, currently the use of the auction revenues is left almost entirely to the discretion of Member States, i.e., there is no legally binding way of forcing a state to invest part of the auction revenue in combating climate change.

In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) was created to raise awareness and build knowledge to help mitigate climate change. In 2013 there were 192 parties to the Kyoto Protocol to the UNFCCC. This set legally binding targets for 37 industrialized countries to limit or reduce overall greenhouse emissions by at least five percent below 1990 levels during the period 2008-2012. During the second commitment period, parties committed to reduce greenhouse emissions by at least 18 percent below 1990 levels in the eight-year period from 2013 to 2020; however, the composition of parties in the second commitment period is different from the first (`http://unfccc.int/kyoto_protocol/items/2830.php`). As an alternative to reducing emissions domestically, industrialized countries (known as Annex 1 countries) can invest in emissions-saving projects in other industrialized countries. An *Emission Reduction Unit* (ERU) represents a transfer from one industrialized country to another, i.e., does not create additional permits. The most common type of compliance credit is a *Certified Emission Reduction Unit* (CER) which originates from projects in non-Annex 1 counties. Certification and overall approval of these abatement projects and their credits is known as the Clean Development Mechanism (CDM).

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[1] The European Commission has established a Market Stability Reserve. The reserve will start operating in 2019. Permits will be added to the reserve if the total number of permits in circulation exceeds 833 million. Back-loaded (postponed) and unallocated permits will also be transferred into the reserve. See European Commission (2015).

There are mixed cases where both permits, emission charges, as well as other policy measures may be used. For example, there are emissions reductions targets for most sectors not covered under the EU ETS. The Effort Sharing Decision (ESD) includes energy supply, industrial energy use and processes, household energy use (in particular, heating), services energy use, transport (road and rail) energy use, waste and agriculture. Consumer behavior also has an impact on emissions counted towards Effort Sharing targets, especially in the transport sector and built environment. Emissions from land use, land-use change and forestry, and international shipping are excluded. The emissions targets for these non-ETS sectors are set for each Member State. Emission permits are allocated to Member States who are responsible for implementing national actions. The overall EU 2020 reduction target is 10 percent below 2005 emissions. Member States are permitted to carry forward a limited amount of permits (Annual Emission Allocations, AEAs) from the following year and carry over any unused permits to subsequent years. They are also permitted to purchase a limited amount of international credits (CERs and ERUs) every year. Member States can sell the unused Annual Emission Allocations and international credits during a reporting year to other Member States and a limited amount from future years to other Member States. Finally, a Member State is allowed to phase out or cancel any surplus of permits.[2]

There are cap-and-trade systems also for other emissions. An example is provided by the US Acid Rain Program to reduce emissions of sulfur dioxide and nitrogen oxides. There are also cap-and-trade systems in other fields, for example, in fishery and for taxicabs. In addition, some countries like Australia, Italy, Norway, Sweden, the UK, and many US States, have introduced so-called *green* certificates (often referred to as electricity or (renewable) energy certificates or (in the US) renewable portfolio standards). These tradable certificates are used to ensure that a specified proportion of electricity comes from (certain types of) renewable sources. There are also so-called tradable *white* certificate schemes. This is a quite new phenomenon. The idea is to achieve energy-saving targets or secure energy supply. Suppliers who overachieve their targets can sell the surpluses to other suppliers or distributors. Refer to Oikonomou and Mundaca (2008) for detailed discussion.

The main purpose of this paper is to discuss how to design a cost–benefit analysis (CBA) of a project within different kinds of cap-and-trade-systems (and a system with green certificates). One reason for undertaking this exercise is that some of the leading cost–benefit manuals provide conflicting recommendations or are silent with respect to the treatment of permits. According to Johansson (2015), both the Canadian manual and the manual of the US Environmental Protection Agency (EPA) view the cost of permits as a pure transfer between firms, i.e., there is no cost to society as a whole. (Treasury Board of Canada Secretariat (2007, p. 10); US EPA (2010, p. 9-16).) The 2014 guide by

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[2] The Effort Sharing Decision covers the six greenhouse gases controlled by the Kyoto Protocol during its first commitment period (2008-2012): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). See `http://ec.europa.eu/clima/policies/effort/index_en.htm`

the European Commission's Directorate-General for Regional and Urban Policy argues that if a dynamic perspective is adopted, a project under evaluation should be credited for any future reduction of the number of permits valued at a shadow price reflecting the damage caused by emissions. (European Commission (2014, p. 225, footnote 266, p. 63, Table 2.10).) To the best of my knowledge, the European Investment Bank is currently (April 2016) assessing how to handle permits, but see European Investment Bank (2013) for latest available approaches. The UK Green Book, see UK Government (2011), was updated in 2014 to value emissions within the EU ETS using the permit price (i.e., not the global marginal damage cost). As far as I can see, the update does not explicitly address the question how a project within the EU ETS affects emissions. However, the 2009 background report quite clearly states that there are binding targets, i.e., no net impact on emissions within the EU ETS. Refer to UK Government (2014, pp. 8-9) and UK Government (2009, p. 24). The Asian Development Bank's guide from 2013 and the Australian Government's handbook from 2006 do not address the issue at all. (Asian Development Bank (2013); Australia Government (2006).) Checks of leading textbooks on environmental and public economics, searches on Google Scholar, and contacts with some leading academic cost–benefit analysts failed to provide any more guidance; the only exception seems to be a short section in the textbook by Johansson and Kriström (2015). This provides further justification for developing this paper. In contrast to Johansson (2015), the current paper discusses some other cap-and-trade systems in addition to the EU ETS plus how to handle green certificates in cost–benefit analysis. Numerical illustrations to many of the results are found in Johansson (2016).

The design of a permit system has a significant distributional impact; see, for example, the recent assessment of the efficiency of the EU ETS by Laing et al. (2013). Allocating permits to firms free of charge (grandfathering) will result in a distribution that is different from the one generated when permits are auctioned. The impression is that the Union is moving from grandfathering towards auctions. In this paper, it is typically assumed that an auction mechanism is applied and that the revenue stays with the national government. Setting aside distributional issues, the auction-assumption has no impact upon the results. I will also introduce a unit tax on emissions of greenhouse gases in a region covered by another and more complex permit system than the EU ETS. The revenues from a tax or a permit system open up the possibility to cut other harmful taxes. However, for most of the part, it is assumed that any revenue is returned to individuals in a lump-sum fashion, but in Section 7 auction revenue is invested to combat climate change.

The paper is structured as follows. Section 2 provides the simple general equilibrium model used with minor modifications throughout the paper. Section 3 presents the basic cost-benefit rule for a project involving tradable permits, but also a rule of the benefits and costs associated with a reduction in the number of permits. A remaining question is if the permit price can be given a meaningful economic interpretation. This issue is addressed in Section 4. Section 5 provides a simple numerical illustration of the possible bias incurred when using wrong approaches to the valuation of tradable permits. The paper then turns to a more complex permit system that is in force for most EU non-ETS sectors, dating back to the Kyoto Protocol. This is done in Section 6, where in addition a unit tax on emissions of greenhouse gases is introduced. The implications of a mandatory rule that forces a country to invest part of its revenue from selling permits in combating climate change are addressed in Section 7. Section 8 introduces emissions of sulfur dioxide (and other gases) causing acid rain. The section introduces both a unit tax and a permit system to combat the externality. In Section 9, the paper takes a brief look at two systems related to permits, namely electricity certificates that are introduced to promote the production of "green" electricity or a reduction of energy consumption. Finally, Section 10 provides a few concluding remarks. An appendix introduces a cap on the aggregate supply of a commodity (say, the total catch of a fish species).

Both cap-and-trade systems and green and white certificates are designed in different ways in different countries/regions. It is impossible to cover all possible cases in a single paper. The main idea is to focus on (simplified versions of) the systems applied in the EU. With respect to green certificates, the approach used in the paper is inspired by the Swedish system. Refer to `https://www.energimyndigheten.se/en` for further details of how the (nowadays common Swedish-Norwegian) certificate market is designed. The white certificates are modeled without reference to any specific country.

2 The Basic Model

In this section, the simple general equilibrium model behind the cost–benefit rules presented in this paper is outlined. For more detailed derivations of cost–benefit rules, the reader is referred to, for example, Drèze and Stern (1987), de Rus (2010), Florio (2014), and Johansson and Kriström (2015). In order to focus on the treatment of permits, distributional issues are set aside. Therefore, there is just a single, representative household. This household is equipped with the following indirect utility function, which also acts as the social welfare function:

$$V = V(\mathbf{P}, y, z, G), \tag{1}$$

where $\mathbf{P}$ is a vector of commodity prices, y is lump-sum income, z is a public good, say, infrastructure, and G represents (the stock of) greenhouse gases. There are several different greenhouse gases with distinct properties, but for notational simplicity it is assumed that they can be aggregated as in equation (1). Scientists prefer to speak of carbon rather than carbon dioxide, but on the European Energy Exchange (EEX) spot market, permits are priced in EUR per metric ton of CO_2; one ton of carbon equals $44/12 = 3.67$ tons of carbon dioxide. For the moment, emissions of other substances, for example, sulfur dioxide are ignored.

Let us consider a kind of aggregate private sector that needs permits. The sector is modeled in the following simple manner:

$$\pi = p^x \cdot f(r, e, G) - p^r \cdot r - p^e \cdot e - P \cdot [g(e) - e^{cm}] - c^c(e^{cm}) + P \cdot \bar{X}, \quad (2)$$

where p^x is the price of the output, $x = f(.)$ is a well-behaved production function, with $\partial f(.)/\partial G = f_G(.) \gtreqless 0$, as some parts of the economy may gain from more greenhouse gases while other may lose, p^r is the price of a renewable input, r is demand for the renewable input, p^e is the price of the single fossil fuel, e is demand for the fossil fuel, P is the permit price per ton emitted, $e^m = g(e)$ is the number of tons of greenhouse gases emitted as a function of the number of tons of fossil fuel the sector uses, $c(e^{cm})$ is an abatement or control cost function, e^{cm} is the amount controlled, and $\bar{X}$ is the lump-sum allocation or grandfathering of permits to the sector. For notational simplicity $\bar{X}$ is set equal to zero in what follows. It seems legitimate to assume that the marginal emission factor, i.e., $g_e(.)$, where a subscript refers to a derivative, is constant (although it varies across different fossil fuels, as is discussed in, for example, the Australian Government (2014)). Therefore, one can rescale the permit price such that $P = p/g_e$, and write the permit cost as $p(e(.) - e^c)$, where $e^{cm} = g_e \cdot e^c$, and the control cost function as $c(e^c) = c^c(e^{cm})$. Assuming that the sector treats all prices as exogenous, profit maximization will result in a profit function:

$$\begin{aligned} \pi(p^x, p^r, p^e, p, G) \equiv & p^x \cdot x(p^x, p^r, p^e, p, G) - p^r \cdot r(p^x, p^r, p^e, p, G) \\ & - (p^e + p) \cdot e(p^x, p^r, p^e, p, G) + p \cdot g(p) - c[g(p)], \end{aligned} \quad (3)$$

where the abatement cost function $c[g(p)]$, with $e^c = g(p)$, is obtained by using the fact that the sector abates until the marginal abatement cost is equal to the permit price, and then turns to purchasing permits. In these functions, p and p^e appear as separate arguments, but one could as well merge them to a single argument $p + p^e$. The sector may use other resources as inputs, but they are not needed in the analysis to follow and hence they are suppressed. For the same reason, all other private firms in this model economy are suppressed. There are also firms producing the inputs. By assuming that the price of the fossil fuel is determined in world markets, we can abstain from modeling the supply.

The renewable input is simply harvested without needing any variable inputs. The profits of the representative producer are:

$$\pi^r(p^r) = p^r \cdot r^s(p^r), \quad (4)$$

ignoring any impact of greenhouse gases on the harvest.

The public sector is modeled in the following simple way:

$$T = p \cdot e^B - (p^e + p) \cdot e^z + p \cdot e^{cz} - c(e^{cz}) - p^r \cdot r^z, \quad (5)$$

where T is a lump-sum payment/tax, e^B is the fixed number of permits, converted to fuel units by using the emission factor g_e, and the public sector uses the fossil fuel, denoted e^z, and the renewable input, denoted r^z, to produce the public good, which is provided free of charge. It abates e^{cz} units of emission at a cost equal to $c(e^{cz})$. In terms of the EU ETS, it is assumed that the system covers the public good under consideration. Note that the public sector, just like a family, cannot earn money by selling to itself. Therefore, net permit income is obtained by deducting from $p \cdot e^B$ the cost of the permits used up by the public sector.

Finally, lump-sum income y in the social welfare function (A.1) has the following components:

$$y \equiv \pi(p^x, p^r, p^e, p, G) + \pi^r(p^r) + T, \tag{6}$$

where profits by other private firms than the considered sector are suppressed. The representative household is assumed to treat all prices as well as profit income as fixed, although (some or all relative) prices, and hence also profits, are endogenous from the point of view of the economy.

An equilibrium in the permit market is reached when the permit price is such that:

$$e(p; p^x, p^r, p^e, G) - g(p) + e^z - e^{cz} = e^B. \tag{7}$$

The price p is such that total private sector plus public sector demand for permits equals the issued number of permits within the bubble, i.e., e^B, holding all other prices and emissions constant. If the abatement technology becomes cheaper due to technological progress, the permit price would adjust (fall) so that all available permits are demanded/purchased while total emissions remain constant; the demand curve for permits shifts to the left while the supply of permits remains unchanged, assuming that final demand is so large that the constraint on supply continues to "bite" (i.e., that the final permit price is strictly positive). Similarly, subsidies aimed at increasing supply of renewable alternatives, such as wind energy and solar panels, will cause the permit price to fall, *ceteris paribus*, but leave emissions unchanged.

A distinction is made between emissions by agents located within the considered bubble, and emissions by agents located in other parts of the world, denoted e^R. Thus, it is assumed that total global emissions equal (in fuel units) $G = e^B + e^R$.

Finally, let us consider the partial derivatives of the social welfare function with respect to a couple of prices. Drawing on the Envelope Theorem, see Johansson and Kriström (2015), the following properties are easily established:

$$\begin{aligned} \frac{\partial V(.)}{\partial p} &= -[e(.) - e^c] - [e^z - e^{cz}] + e^B = 0 \\ \frac{\partial V(.)}{\partial p^r} &= r^s(.) - r(.) - r^z = 0. \end{aligned} \tag{8}$$

Thus, if prices clear markets, a small adjustment of a price leaves no fingerprint with respect to welfare. The implication for cost–benefit analysis is that one can ignore the induced price adjustments a small project causes. In the first line of equation (8), the first (second) term within brackets yields private (public) sector demand for permits; demand for permits is equal to gross emissions less the amount abated. In equilibrium this aggregate demand equals the fixed “supply” of permits. Similarly, in equilibrium, aggregate demand for the renewable input equals supply of the input. The same will hold true for any other output/input whose price is flexible.

3 The Basic Cost–Benefit Rules

Consider now a marginal increase in the provision of the public good. A fossil fuel and a renewable resource are used as inputs. This project, even if marginal, will cause small price adjustments in order to move the economy from one general equilibrium to another. However, equation (8) reveals that such induced price movements have no welfare implications within the present context. Therefore, marginally increasing z, e^z, r^z, and e^{cz}, one arrives at the following cost–benefit rule, after multiplication by the inverse of the marginal utility of lump-sum income:

$$\begin{aligned}\frac{dV}{V_y(.)} =& \frac{V_z(.)}{V_y(.)}dz - [(p+p^e)de^z - (p - c_{e^{cz}})de^{cz} + p^r dr^z] \\ &+ [p^x \cdot f_G(.) + \frac{V_G(.)}{V_y(.)}]de^R, \end{aligned} \tag{9}$$

where $V_y(.)$ is the marginal utility of lump-sum income, $V_z(.)$ is the marginal utility of the public good, and $c_{e^{cz}}$ is the public sector’s marginal abatement cost.

The first term on the right-hand side of (9) yields the marginal willingness-to-pay for the public good. The first term within parenthesis yields the cost of the fossil fuel if there is no abatement technology available, while the second term within parenthesis accounts for such a technology. If this marginal abatement cost is equal to the permit price, one can evaluate the fossil fuel as $(p+p^e)de^z$. However, it is not necessarily true that the public sector is a cost-minimizer. The final term in the first line accounts for the cost of the renewable input.

The second line in (9) covers any change in emissions of greenhouse gases outside the considered area; recall that there is a fixed number of permits within the bubble, implying that $de^B = 0$. The first term within brackets in the second line covers any gain or loss in the value of the marginal product of the private sector due to $de^R \neq 0$. The final term within brackets captures the positive (negative) household WTP for marginally less (more) emissions.

Note that the cost–benefit expression, i.e. the right-hand side of equation (9), is *proportional* to the *unobservable* change in welfare caused by the considered small project. Thus, the cost-benefit expression is a sign-preserving measure of the underlying change in welfare. Setting aside any change in global emissions, the optimal provision of the public good is such that the marginal WTP for the good is equal to the marginal cost of providing the good. In a multi-household society, the Samuelson (1954) rule reads: the sum of the marginal willingnesses-to-pay should equal the marginal cost. If the marginal WTP exceeds (falls short of) the marginal cost, the cost–benefit analysis signals that more (less) of the good should be provided.

Summing up this basic case for the handling of tradable permits in cost–benefit analysis, the following evaluation rules apply:

- Value an increase (decrease) in the provision of the public good at the aggregate positive (negative) willingness-to-pay.
- Value all inputs, including permits at initial prices.
- Account for any divergence between the permit price and marginal abatement costs for abated amounts of emissions.
- The project has no impact on total emissions of greenhouse gases within the bubble (say, EU ETS).
- If the project has an impact on emissions outside the bubble, value the impact using an estimate of the marginal damage cost.

In an intertemporal world, one would simply evaluate each item as a present value.

The following examples illustrate how the project could affect emissions outside the permit system.

- The project may displace a competitor not covered by a cap-and-trade system. This, which may occur inside or outside the region covered by the permit system, reduces global emissions.
- The project may impact on the harvest of coal, natural gas, or oil, outside regions covered by cap-and-trade systems, and the extraction of these fuels generate emissions of greenhouse gases.

Within limits, companies can also buy credits from certain types of approved emission-saving projects around the world. Then the cost is represented not by a permit price but by what they pay for these credits. These projects must be recognized under the Kyoto Protocols Clean Development Mechanism or Joint Implementation Mechanism as bringing real and genuinely additional emission reductions.

In an open economy context, permits may be purchased from other agents than the domestic government. If so, one could argue that the foreign currency needed for purchasing the permits, in the long run must be earned by exporting more goods and services. Thus, there is a permit cost also in this case.

4 On the Interpretation of the Permit Price

Thus far, we have not provided any interpretation of the permit price, nor discussed why that price is used rather than the marginal damage cost. In order to provide answers to these issues, consider a marginal reduction in the number of permits. Holding z and e^R constant, the cost–benefit analysis reads:

$$\frac{dV}{V_y(.)} = [p + p^x \cdot f_G(.) + \frac{V_G(.)}{V_y(.)}]de^B, \tag{10}$$

where $V_G(.)$ is assumed to be strictly negative, and $de^B < 0$. Thus, as long as the damage costs exceed the permit price, the reduction is socially profitable.

As is obvious from equation (10), the permit price does not reflect marginal damage costs of greenhouse gases, unless the number of permits is at its optimal level. In order to provide an interpretation, consider instead equation (2) after having rescaled emissions in the way discussed below the equation. A necessary condition for profit maximization is as follows:

$$p^x \cdot f_e(.) = p + p^e \tag{11}$$

where $f_e(.) = \partial f(.)/\partial e$. Thus, in optimum the value of the marginal product of the composite input, consisting of the fuel and the emissions, equals the price of the composite input. As a consequence, one can replace $p + p^e$ in equation (9) by the value of the marginal product *displaced* elsewhere in the economy. This provides a neat interpretation of the cost of using a fossil input under a cap-and-trade system; by necessity, the activity must displace another user of permits.

According to equation (10), the representative agent is a *pure egoist* in the sense that any costs inflicted upon people living outside the bubble are neglected. Things would be different if the agent is a *pure altruist*. Then the agent would include the indirect utility function of the representative "outsider" household as an argument in its own indirect utility function. In this case, the equations would be augmented with terms representing the marginal impact of domestic policies on foreigners. In this sense, the cost–benefit analysis would reflect the global benefits and costs of a policy. For a recent discussion of whom stands in cost–benefit analysis, refer to Johansson and de Rus (2015).

Summing up, we have the following results.

- The permit price reflects the value of the marginal product of the composite input consisting of the fossil fuel and emissions that is displaced elsewhere in the economy.
- The value of a permit deviates from the marginal damage cost of greenhouse gases, except if the number of permits is set at its optimal level. What is meant by an "optimal" level depends on who counts (stands) in cost–benefit analysis.

5 On the Bias incurred by Using Erroneous Approaches

According to Section 1, leading international cost-benefit guides handle tradable permits erroneously. Some claim that they are pure transfers and hence can be ignored. Others claim that permits should be valued at the marginal damage cost caused by greenhouse gases. The only manual that seems to use the approach of the current paper is the UK Green Book. Refer to UK Government (2014).

In order to provide a simple illustration of the possible magnitude of the bias caused by using an erroneous approach, consider a steel plant of typical size that will produce 2 million metric tons of steel per annum[3] and emit 4 million tons of greenhouse gases; emission factors vary from 1.25 to 3.8 according to Metz et al. (2007, p. 461) but is arbitrarily set equal to 2 here (as for e.g. Sweden and the US). Some manuals would ignore these emissions, considering them to be transfers between plants. According to this paper, the annual cost is USD 40 million if the permit price is USD 10/ton; during recent years the EU ETS permit price has typically been USD 5-10. If the emissions are valued at a marginal damage cost of USD 64/ton, the fitted mean value of all studies in Tol (2009, Table 2), the cost is USD 256 million.[4] Thus, estimates fall in the interval USD 0-256 million. Suppose that the base case cost-benefit analysis, exclusive of permits/emissions, shows a surplus equal to USD 40 million per annum, expressed as an annuity. Then we have three different answers to whether the plant is socially profitable or not, although only the break-even result is correct.

Moreover, estimates of the social marginal damage cost vary hugely, from a few USD to USD 620-780 per metric ton of CO_2-emissions according to Tol (2009, Table 2), while Ackerman and Stanton (2014, p. 151) claim that the cost could be almost USD 1,030/tCO_2 in 2010, rising to more than USD 1,700/tCO_2 in 2050. Therefore, a sensitivity analysis is likely to deepen the difference between the approach used throughout this paper and an approach valuing emissions at the marginal damage cost of carbon.

6 Mixed Cases

In this section we turn to a slightly more complex cap-and-trade system than the one discussed previously. The aim is to outline a blueprint of the system that is in force for most non-ETS sectors. There are emissions targets for each Member State. Emission permits are allocated to Member States who are responsible for implementing national actions. They are also permitted to purchase a limited amount of international credits (CERs and ERUs) every year. Member States can sell the unused Annual Emission Allocations and international credits during a reporting year to other Member States.

In order to proceed, it is assumed that the fossil fuel no longer is covered by the permit system. Instead there is a *unit* tax t on emissions caused by using

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[3] For example, in 2013 US Steel's smallest domestic facility, Fairfield Works, located 10 miles west of Birmingham, AL, had an annual raw steel-making capability of approximately 2.2 million metric tons; `https://www.ussteel.com/uss/portal/home/aboutus/facilities`.

[4] All prices have been converted into 2015 dollars. The 2015 marginal damage cost used by the US EPA is USD 41 at a discount rate of 3 percent, but the cost increases to USD 79 in 2050. Refer to US EPA (2015).

the fossil fuel; a unit, rather than an ad valorem, tax simplifies a comparison with the permit system. The profit function is now stated as follows:

$$\begin{aligned}\pi(p^x, p^r, p^e, t, G) \equiv & p^e \cdot x(p^x, p^r, p^e, t, G) - p^r \cdot r(p^x, p^r, p^e, t, G) \\ & - (p^e + t) \cdot e(p^x, p^r, p^e, t, G) + t \cdot g(t) - c[g(t)], \end{aligned} \tag{12}$$

where $g(t)$ is the quantity of emissions abated, as a function of the emissions tax. The sector uses the same inputs as the "ETS sector" considered in equation (3); compare oil used by an oil-fired power plant covered by the ETS and oil refined to gasoline or diesel and used in ground transportation, not covered by the ETS (say, trucks and diesel locomotives). The sector will abate until the marginal abatement cost is equal to the tax, and then turn to emitting greenhouse gases.

The public sector is now modeled in the following way:

$$T = t \cdot [e(.) - g(t)] - p^e \cdot e^z - c(e^{cz}) - p^r \cdot r^z + p^{CER} \cdot (S - \delta \cdot B), \tag{13}$$

where p^{CER} is the price of a Certified Emission Reduction unit, $S \geq 0$ is the country's surplus of such units sold to other countries (while any surplus phased out or canceled generate zero revenue), $\delta = 0$ if $S > 0$, and unity otherwise, and B is the number of CERs purchased if $S = 0$. Emission Reduction Units (ERU) represents a transfer from one industrialized country (Annex-1 country) to another, i.e., do not create additional permits. It is basically an attempt to achieve a cost-efficient distribution of abatement over the participating countries. In other words, the host country cannot include reductions behind ERUs sold in its own emission abatement efforts. Both ERUs and CERs are traded in markets. For simplicity, ERU credits are here seen as a variation of CER credits. The maintained assumption is that all participating industrialized countries face binding emission targets (but are permitted to have more ambitious targets for their climate policies than what agreements legally require).

For this kind of permit system, there are at least four different options in evaluating a marginal increase in the provision of a public good using a fossil fuel and a renewable as inputs, just as before. Assume that the surplus S is sufficiently large to compensate for the extra emissions of greenhouse gases caused by the project. Then the cost–benefit rule reads:

$$\begin{aligned}\frac{dV}{V_y(.)} = & \frac{V_z(.)}{V_y(.)} dz - [(p^e + p^{CER}) de^z + (c_{e^{cz}} - p^{CER}) de^{cz} + p^r dr^z] \\ & + t \cdot (de - c_{g(t)} dg) + [p^x \cdot f_G(.) + \frac{V_G(.)}{V_y(.)}] de^I, \end{aligned} \tag{14}$$

where $de^z - de^{cz} = -dS$ (plus any induced private sector emissions, as covered by the first term within parenthesis in the second line of the equation), and de^I refers to any *indirect* change in emissions caused by the project, for example, when the fossil fuel is harvested (but note that the supply of energy within the Union is covered by the permit system under discussion in this section). The country will sell fewer CERs (ERUs) because a number of such units are needed in compensating for the extra emissions caused by the considered project.

Emissions within the considered area (say, EU or Annex-1 countries) increases if the international credit units are obtained through an emissions-saving project in a developing country, but the direct impact on global emissions is zero also in this case. Note that the final term within parenthesis in the first line of (14) equals zero if the considered project is socially cost-efficient in its abatement strategy. However, at the plant level the permit system under consideration does not seem to provide any incentives to undertake abatement measures.

A parallel case occurs if the country must purchase credits (and has not reached the limit for such purchases) to compensate for the project. Then, $de^z - de^{cz} = dB$ and one can evaluate the project just as in equation (14). Alternatively, if $t = 0$, in both cases the rule stated in Section 3 applies (with p replaced by p^{CER}), but recall the difference in incentives at the individual plant level between the two types of permits/credits.

Suppose next that the country instead cancels or phases out any surplus of international credits, i.e., the magnitude of the surplus is "endogenous". This is equivalent to setting p^{CER} equal to zero in equation (14). Now the evaluation rule reads:

$$\begin{aligned}\frac{dV}{V_y(.)} =& \frac{V_z(.)}{V_y(.)}dz - [p^e de^z + c_{e^{cz}} de^{cz} + p^r dr^z] \\ &+ [p^x \cdot f_G(.) + \frac{V_G(.)}{V_y(.)}]dG. \end{aligned} \tag{15}$$

For notational simplicity, any changes in tax revenue and emissions originating from the private sector are ignored. The project simply enables the country to phase out $de^z - de^{cz} = dS$ fewer permits, and hence reduces the over-achievement of the overall area (EU/Annex-1 countries) target. In other words, emissions increase in comparison to the counterfactual. Therefore, the project's emission cost is obtained by multiplying the "shadow price" of emissions by $dG = (de^z - de^{cz} + de^R)$. (To the best of my knowledge, if an agent possessing EU ETS-permits register them as cancelled, they will be replaced. In order to achieve a reduction of emissions, the agent should store the permits in his/her bank vault.)

If the country has a target for its emissions, a final opportunity is to increase the tax so as to keep total emissions constant. Consider the welfare impact of a marginal increase in the tax:

$$\begin{aligned}\frac{\partial V}{\partial t} &= -e(.) + g(t) + e(.) - g(t) + t \cdot [e_t(.) - g_t(.)] \\ &= t \cdot [e_t(.) - g_t(.)], \end{aligned} \tag{16}$$

where a subscript t refers to a derivative with respect to the tax. In order for emissions to remain constant, it must hold that $[e_t(.) - g_t(.)]dt = de^z - c_{e^{cz}} de^{cz}$, assuming that a marginal tax increase is sufficient to achieve the target when the project is small or marginal. In this case, the cost of the fossil fuel is $p^e + t$.

The evaluation rule can be state as follows:

$$\frac{dV}{V_y(.)} = \frac{V_z(.)}{V_y(.)}dz - [(p^e + t)de^z + (c_{e^{cz}} - t)de^{cz} + p^r dr^z] + [p^x \cdot f_G(.) + \frac{V_G(.)}{V_y(.)}]de^R. \tag{17}$$

Note that if the public sector is cost-efficient in its abatement strategy, the tax can be replaced by the marginal abatement cost. If so, the term $c_{e^{cz}} - t$ in the equation is equal to zero. This case is very similar to the "ETS-permit" case considered in Section 3.

Summing up the different cases, the following evaluation rules apply.

- A country has a surplus of permits that is sold. The considered project has no impact on emissions of greenhouse gases (except through de^I). The revenue lost from selling fewer permits, rather than the cost of acquiring permits, must be added to the cost–benefit analysis.
- A country is permitted to acquire a limited amount of international credits by undertaking emissions-reducing projects in other countries. In this case, there will be no extra emissions (except through de^I). The cost of acquiring the credits represents the social cost. The cost may be quite low, in particular, if the credit-earning project is undertaken in a developing country, where marginal abatement costs often are claimed to be lower than in developed countries (Cricui et al. (1991)).
- A country has a surplus of permits and phases out surplus-permits (as is done by some Member States). Then value the additional emissions caused by the project at the marginal damage cost.
- A country decides to increase the tax on fossil fuels to keep emissions constant. Then, the considered project has no impact on total emissions within the bubble. The fossil fuel is valued at the fuel price plus the tax rate (or the marginal abatement cost, assuming that the project has a cost-efficient abatement strategy).

7 Investing Permit Revenue to Combat Climate Change

As mentioned in Section 1, at least half of auctioning revenues, and all the revenues from auctioning permits to the aviation sector, should be used to combat climate change (although a binding legislation is missing). Suppose that x percent of permit revenue is invested for such purposes. Then the relevant part of the budget constraint is reformulated to read:

$$p \cdot [e^B - e^z + e^{cz}] - x \cdot p \cdot [e^B - e^z + e^{cz}]. \tag{18}$$

Suppose that x percent of the permit revenue is invested in sectors covered by the EU ETS, say, in wind and solar power. Because there is a cap on total emissions, from an economic point of view, this is a sheer waste of resources. The public sector project under evaluation reduces permit revenue and hence the waste. Therefore, the cost of using the fossil fuel is now:

$$C^f = (p^e + p)de^z - x \cdot p \cdot (de^z - de^{cz}), \tag{19}$$

where it is assumed that the project abates in a cost-efficient manner. Thus, in this scenario where permit income is invested in the bubble (EU ETS), the project's impact is as follows.

- The project has no impact on emissions within the bubble.
- Value permits at the permit price.
- Deduct a term reflecting that fewer resources are wasted.

The outcome is more diverse if the revenue is invested in EU non-ETS sectors. The loss of revenue for such measures can be compensated by selling fewer international credits (if the country has a surplus) or purchasing additional units. Alternatively, the country could increase the emission tax to compensate for the loss of permit revenue. In these cases, there is no change in emissions of greenhouse gases, and one could proceed as in equation (9), drawing on the simplifying assumption that all involved emission-saving measures are equally costly.[5]

Summing up these cases where the loss of permit revenue is handled by selling fewer or buying additional international credits or by increasing the emission charge, one has the following impacts.

- The project has no impact on emissions within the bubble.
- Value permits at the permit price.

In contrast, if the country has a surplus of credits that is phased out (or all countries have surpluses so that the price of a credit equals zero), and no fixed target for its emissions, the surplus is endogenous and simply deteriorates, causing global emissions to increase. Then value permits as in equation (19), and add the marginal damage cost caused by the reduction of the permit revenue that is set aside for combating climate change $(-x \cdot (pde^z - pde^{cz}))$.

Thus, in the case where any surplus of international credits is phased out, one has:

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[5] Ignoring abatement costs for the considered project, suppose $\bar{e} = e^n + e^i - x \cdot (e^B - e^z) - e^o$, where $\bar{e}$ is the target for EU non-ETS emissions, e^n refers to domestic emissions, e^i is the positive (to be sold) or negative (to be purchased) surplus of international credits, $x \cdot (e^B - e^z)$ of permit revenue is invested to combat climate change, and e^o refers to other measures undertaken to combat emissions. A change in e^z causes a neutralizing adjustment in the number of credits sold/purchased or in domestic measures (possibly financed by a tax increase).

- Value permits at the permit price.
- Add a term reflecting the cost of additional damage due to less investment in combating climate change.

8 Acid Rain

The considered project may also contribute to acid rain through emissions of sulfur dioxide and nitrogen oxides. Acid rain causes acidification of lakes and streams and contributes to the damage of trees at high elevations and many sensitive forest soils. In addition, acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of a nation's cultural heritage. Many scientific studies have identified a relationship between elevated levels of fine particles and increased illness and premature death from heart and lung disorders, such as asthma and bronchitis.

Unless the emissions causing acid rain are taxed such that the externality is internalized, one must add a cost item reflecting the marginal damage cost to the cost-benefit expression. This can be done as follows, assuming there is a permit system for greenhouse gases while there is an emission charge on gases causing acid rain:

$$\begin{aligned}\frac{dV}{V_y(.)} =& \frac{V_z(.)}{V_y(.)}dz - [(p^e + p)de^z + p^r dr^z] \\ &+ [p^x \cdot f_G(.) + \frac{V_G(.)}{V_y(.)}]de^R + [p^x \cdot f_A(.) + \frac{V_A(.)}{V_y(.)}]dA, \qquad (20)\end{aligned}$$

where a subscript A refers to a derivative with respect to acid rain, dA is a function of the amount of the fossil fuel used up by the firm, it is assumed that the public sector firm is cost-effective in its abatement of both kinds of emissions, i.e., abates greenhouse gases until the marginal abatement cost equals the permit price, and abates gases causing acid rain until the marginal abatement cost equals the emission tax, and induced adjustments in the private sector are ignored. Thus, the cost-benefit practitioner must account for the damage on production caused by acid rain plus the damage caused to human beings. If emissions are "exported" (taken by winds) to other countries, it may be necessary to account for the associated damage, at least if those living in the considered project's host country are altruists. Thus, the cost-benefit rule reads:

- If there is an emission tax on SO_2 (and NO_x), value emissions caused by the project at the marginal damage cost associated with sulfur dioxide (nitrogen oxides).
- If emissions are taken by winds to other countries, it may be necessary to add the cost of damage in these countries, at least if those living in the "exporting" country are altruists.

If the emission tax is replaced by a permit system, as in the US, the cost-benefit rule would read:

$$\begin{aligned}\frac{dV}{V_y(.)} =& \frac{V_z(.)}{V_y(.)}dz - [(p^e + p + p^A)de^z + p^r dr^z] \\ &+ [p^x \cdot f_G(.) + \frac{V_G(.)}{V_y(.)}]de^R,\end{aligned} \tag{21}$$

where p^A is the price of a sulfur dioxide (or nitrogen oxide) permit, rescaled so as to relate to a metric ton of the fossil fuel. Because there is a fixed number of such permits, the project does not cause additional acid rain. The interpretation of p^A parallels the interpretation of p in Section 4. Now the evaluation rule reads:

- If there is a permit system for SO_2 (and/or NO_x), value permits at the permit price.
- The project has no impact on acid rain (if all causes related to the fossil fuel are subject to caps).

9 Green and White Certificates

Some countries have introduced *electricity certificates*, here often referred to as green certificates. These are a financial support for the production of electricity from renewable energy. The market participants with quota obligations are primarily power suppliers. These must purchase electricity certificates each year corresponding to a certain proportion of their electricity deliveries or consumption, the so-called quota obligation. The quota curve states how great a proportion of the calculation-relevant electricity consumption the market participants with quota obligations must purchase electricity certificates for each year. In this section a sketch of a certificate system is outlined. Refer to Böhringer and Rosendahl (2010) for an analysis showing that a green quota, i.e., green certificates, imposed on top of a black quota, i.e., tradable permit system, promotes power production by the dirtiest technologies as compared to a black quota regime only. The first part of this section draws on Kriström (2016) who undertakes a cost-benefit analysis of green certificates with some numerical illustrations for Sweden.

Assume that the representative consumer has to purchase $0 < \alpha < 1$ percent certificates for each unit of electricity consumed. The price of a kWh of electricity equals:

$$p^c = p^s + \alpha \cdot p^g, \tag{22}$$

where p^c is the consumer price of electricity, p^s is the spot price, p^g is the certificate price, and any variable charge for transmission of electricity is ignored. The ratio α is defined as follows:

$$\alpha = \frac{x^g(p^s + p^g) + x^{gg}}{x^g(p^s + p^g) + x^{gg} + x^f(p^s) + x^{fg}}, \tag{23}$$

where $x^g(.)$ is the private sector supply of "green" electricity, x^{gg} is public sector supply of such electricity, $x^f(.)$ is the private sector supply of fossil-fueled electricity, and x^{fg} is public sector supply of such electricity. The exogenous public sector firms are introduced just in order to generate cost–benefit rules. The ratio α is determined by the government, implying that prices have to adjust so that the proportion green electricity reaches the target.[6] Here permits are ignored, but the spot price will reflect the permit price if fossil-fueled power stations are marginal in the electricity market.

The representative household is now equipped with the following simple indirect utility function:

$$V = V(p^s + \alpha \cdot p^g, \pi^g(.) + \pi^f(.) + T), \tag{24}$$

where all prices but the electricity price are suppressed, $\pi^g(.)$ is the profit function of the representative green firm, $\pi^f(.)$ is the profit function of the producer of non-green electricity, and T captures the profits made by public sector producers of electricity.

Consider now a small change in public sector electricity production. All induced price changes can be ignored. Therefore, the cost–benefit rule reduces to:

$$\frac{dV}{V_y} = [(p^s + p^g) - C_{x^{gg}}(.)]dx^{gg} + [p^s - C_{x^{fg}}(.)]dx^{fg}, \tag{25}$$

where $C_{x^{gg}}$ and $C_{x^{fg}}$ are marginal cost functions. Because the share of green electricity must be maintained, equation (25) can be rewritten to read:

$$\begin{aligned}\frac{dV}{V_y} =& [(p^s + p^g) - C_{x^{gg}}(.)] \cdot \alpha \cdot dx^d + [p^s - C_{x^{fg}}(.)] \cdot (1 - \alpha) \cdot dx^d \\ =& [p^s + \alpha \cdot p^g]dx^d - [\alpha \cdot C_{x^{gg}}(.) + (1 - \alpha) \cdot C_{x^{fg}}(.)]dx^d, \end{aligned} \tag{26}$$

where dx^d is the net change in household demand, here assumed to equal dx^{gg}/α so that $dx^d = dx^{gg} + dx^{fg}$. Thus, a combined change, preserving the ratio of green electricity, is evaluated. The household WTP for an extra kWh is equal to $p^s + \alpha \cdot p^g$. The marginal cost of providing the extra kWh is a weighted average of the marginal costs of the two different electricity generation forms. A useful simplification is obtained by replacing the marginal cost of the alternative (i.e., not under evaluation) type of electricity generation by the alternative's market price, i.e., either p^s or $p^s + p^g$.

Thus, a cost–benefit rule for an electricity system forcing consumers to purchase a certain portion of renewable electricity reads as follows.

- ■ The marginal WTP for electricity is a weighted average of the electricity price and the certificate price.

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[6] In equilibrium supply of electricity is equal to demand. To simultaneously solve for both p^s and p^g, use this market equilibrium condition and equation (23).

- The marginal cost of providing another kWh is a weighted average of the marginal production costs of the different types of plants (ignoring here any variable transmission cost).

The evaluation is simplified if all plants but the one under evaluation are profit maximizing, i.e., produce such that price equals marginal cost. This is seen from the first line of equation (26). The extreme assumption is that all plants, except the one under evaluation, operate with constant marginal costs. Then, one can assume that $dx^d = 0$, and the public sector plant can be viewed as simply displacing private sector supply (of the same type to preserve α unchanged). Hence the gain/loss is captured by the difference between the price received and the marginal cost of providing x^{gg} (or x^{fg}) times dx^{gg} (or dx^{fg}).

From the above cost–benefit rule, one may get the impression that certificates come without costs. However, differentiating the social welfare function (24) with respect to α one arrives at the following expression:

$$\frac{dV}{V_y} = -x^d(.) \cdot p^g \cdot d\alpha. \tag{27}$$

Thus, there is a welfare cost associated with introducing certificates. They simply distort the market mechanism. However, if the system causes acid rain to reduce, there is also a benefit (assuming that there is a cap-and-trade system for greenhouse gases), but, at least in Sweden, nuclear power plants and some hydropower plants are not eligible for certificates.

Finally, we turn to white certificates. These are also referred to as energy savings certificates or energy efficiency credits. The basic idea is that energy suppliers and distributors must fulfill specific energy-saving targets by implementing energy-efficiency measures for their customers. Energy suppliers or distributors who save more energy than their targets can sell the surplus in the form of white certificates to suppliers/distributors who cannot fulfill their targets. There are such schemes in (at least) Italy, France, the UK, and some states in the US.

Consider a public sector firm supplying electricity. The profit function is stated as follows:

$$\pi^e = p^s \cdot x^e - C(x^e) - C^e(E) - p^w \cdot (\bar{E} - E), \tag{28}$$

where p^s is the electricity price, x^e is the quantity of electricity supplied by the considered public sector firm, $C(.)$ is a cost function reflecting the cost of producing/distributing electricity, $C^e(.)$ is a cost function reflecting the cost of undertaking energy-saving measures, E, for end users, p^w is the price of a white certificate, and $\bar{E}$ is the energy-saving target faced by the firm. Thus, as modeled here, the firm is required to purchase certificates for a deficit of energy savings, and is allowed to sell a surplus of certificates.

Equilibrium in the market for white certificates requires that the aggregate excess demand is equal to zero:

$$[\bar{E} - E] + \sum_i [\bar{E}^i - E^i(p^w)] = 0. \tag{29}$$

As is seen from equation (30) below, a profit-maximizing firm will undertake energy-saving measures until the marginal cost of such measures equals the certificate price and then sell any surplus (or purchase certificates to cover a deficit). This explains that private-sector firms have demand functions for energy-saving measures having the certificate price as (sole) argument.

If the public sector firm in equation (28) marginally increases its production and energy-saving, the cost-benefit rule is as follows:

$$\frac{dV}{V_y} = [p^s - C_{x^e}(.)]dx^e + (p^w - C_E^e(.)]dE. \tag{30}$$

If the firm maximizes profits, it will supply a quantity such that the marginal cost of producing electricity is equal to the electricity price and undertake energy-saving measures until the marginal cost of such measures is equal to the certificate price.

Consider next a small increase in the energy-saving target $d\bar{E} = (\partial x^d(.)/\partial \bar{E})\delta \bar{E}$. A cost–benefit analysis reveals the following benefits and costs:

$$\frac{dV}{V_y} = [p^s - p^w]d\bar{E}. \tag{31}$$

The value of saving energy to the consumer is the electricity price, while the supplier is assumed to be profit maximizing and hence save until the marginal cost of such measures equals the certificate price.

- The WTP for a sharpening of the energy-saving target is reflected by the electricity price.
- The marginal cost of further savings is reflected by the price of a white certificate.

Thus, a sharpening of the target is socially motivated if the energy-saving measures are cheaper than the electricity price. However, the electricity price p^s may be distorted by taxes. Assuming that the spot price reflects the marginal production cost and the variable transmission tariff reflects the marginal transmission (and distribution) cost, the sum of these two components replaces the end user electricity price; recall that the government loses tax revenue due to the energy-saving measures. Typically, transmission (and distribution to end users) of electricity is considered a natural monopoly. Assume that this natural monopoly has decreasing average costs, faces a break-even constraint, and uses a two-part tariff, i.e., charges consumers a fixed, one-time fee and a price for each unit purchased. Given this setting, if the firm can set the fixed fee optimally, the variable price equals marginal cost, as assumed above. Refer to Johansson and Kristrm (2012, pp. 24-25 and 104-106) for such an approach, and to Juskow (2007) for an extended discussion of the regulation of natural monopolies. There may be additional benefits in terms of fewer emissions, unless there are tradable permits for all damaging emissions.

10 Conclusions

The purpose of this paper has been to illustrate how to handle cap-and-trade and similar systems in evaluations of projects. If the project is small or marginal, the basic rule is to value permits at their (forecast present value) market price. This price plus the fuel price reflects the value of the marginal product displaced elsewhere in the economy by a project purchasing a permit. If the project is large or non-marginal, the evaluation is slightly more complicated, but a quite obvious generalization of the cost–benefit rule obtained for a small or marginal project. Refer to Johansson (2015) for a brief assessment of the large project case. Regardless of whether the project is small or large, it has no impact on total or aggregate emissions of greenhouse gases within the "bubble" (EU ETS, for example). Therefore, it would be a mistake to value permits at the global marginal damage cost; the damage cost of a zero increase in emissions is zero. Similarly, it would be a mistake to treat permits as a transfer within the private sector.

Reducing the number of permits displaces production whose value is reflected by the permit price. On the other hand, there is a benefit in the form of less damage to firms and households. However, unless the number of permits is at its optimal level, the permit price differs from the marginal damage cost caused by greenhouse gases. It is far from self-evident, that the number of permits within the considered bubble, say, EU ETS, is sufficient to achieve an equality between the permit price and the marginal damage cost. That is, the demand for permits may be zero if the permit price is set equal to the marginal damage cost.

As mentioned in Section 1, under the relevant EU legislation for the EU ETS at least half of auctioning revenues, and all the revenues from auctioning permits to the aviation sector, should be used to combat climate change in Europe or other parts of the world. This system has some peculiar properties. If countries invest in sectors covered by the EU ETS, as some Member States seem to do, a sheer waste of resources occurs. This is so because total emissions of greenhouse gases remain constant. In effect, a polluting project will reduce permit revenue and hence waste. The same outcome occurs if the country has a surplus of international credits that is phased out or canceled. In other cases, there will be no change in total emissions and permits are valued at the permit price, as is discussed in Section 7.

The paper has also illustrated that a cost-benefit analysis may be seriously biased if permits are ignored or valued at the marginal damage cost. In particular, there is huge uncertainty with respect to the magnitude of the marginal damage cost of greenhouse gases. Estimates vary from a few USD up to over 1,000 USD. No corresponding wide range of estimates has been suggested with respect to permit prices. Therefore, a sensitivity analysis is expected to widen the gap between a CBA based on permit prices and one using marginal damage costs.

The paper has discussed the properties of a more complex permit system that reminds of the permit system that is in force for most EU non-ETS sectors, dating back to the Kyoto Protocol. In this case, several types of international credits are traded and can be used to compensate for additional emissions caused by a project. A surplus of credits can either be sold or phased out. In this last case, a polluting project causes emissions of greenhouse gases to increase; the surplus of credits simply shrinks. A country may also increase an emission charge to compensate for an increase in emissions. A particular feature of this kind of permit system is that individual firms do not have to acquire permits, i.e., there seem to be weak incentives at the firm level to abate, unless emission charges are used by countries.

A project using a fossil fuel as input may also contribute to acid rain through emissions of sulfur dioxide and nitrogen oxides. Acid rain causes acidification of lakes and streams and contributes to the damage of trees at high elevations and many sensitive forest soils. In addition, acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of a nation's cultural heritage. Many scientific studies have identified a relationship between elevated levels of fine particles and increased illness and premature death from heart and lung disorders, such as asthma and bronchitis.

If there is an emission tax on SO_2 (and/or NO_x) or no policy instrument at all, value emissions caused by the project at the marginal damage cost associated with sulfur dioxide. If emissions are taken by winds to other countries, it may be necessary to add the cost of damage in these countries, at least if those living in the country "exporting" emissions are altruists. On the other hand, if there is a permit system for SO_2 (and/or NO_x), value permits at the permit price. The project has no impact on acid rain (if all causes related to the fossil fuel are subject to caps).

Finally, some countries have introduced electricity certificates to promote the production of "green" electricity. Such a system stipulates that a certain proportion of electricity consumed must be renewable. Certificates are traded in a market. The implication for cost–benefit analysis is that the marginal WTP for electricity is a weighted average of the electricity price and the certificate price. The marginal cost is a weighted average of the marginal costs of the different kinds of power plants. Certificate systems are associated with real costs because they distort the functioning of the electricity market. A variation is called white certificates. Then the supplier of electricity is forced to undertake energy-saving measures for their customers. Such measures are socially profitable as long as the electricity price exceeds the marginal cost of energy-saving measures.

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Appendix: Caps and Taxes on Outputs

Suppose there is a number of private sector firms plus a public sector firm that produce a commodity whose total supply is limited by the government to not exceed q^0 units. For each unit a permit is required, and it is assumed that the cap is binding. Equilibrium in the output market and the permit market require that:

$$\begin{aligned} q^d(p^q) &= q^0 \\ \sum_f q^f(p^q - p) + q^p &= q^0, \end{aligned} \tag{A.1}$$

where all prices but the output price p^q and the permit price p are suppressed, $q^d(.)$ is demand for the commodity (to avoid path dependency problems the commodity is used as an input), q^0 is the cap on supply and the number of permits, $q^f(.)$ is supply of firm f, and q^p is the exogenous supply of the public sector firm. In this case both the output price p^q and the permit price p must adjust so as to achieve equilibrium in both markets. Equilibrium is achieved when the price vector $[p^q, p]$ is such that supply equals demand in both markets. If p^q is below some critical level, the cap is no longer binding, $p = 0$, and if there is an interior equilibrium then there is a $p > 0$ such that aggregate supply equals q^0.

Conditional on the cap being binding, a change in q^p must be followed by private sector adjustments such that total supply remains equal to the cap set by the government. This is achieved by adjustments of the permit price. This price reflects the maximal amount of money the marginal permit purchaser can afford to pay. Hence, a cost–benefit analysis will reflect any difference in operating costs between the firms, as well as any difference in emissions (say, if two fishing vessels operate with different engines and/or fuels).

An emission charge is modeled as follows:

$$q^d(p^q) = \sum_f q^f(p^q - t) + q^p. \tag{A.2}$$

Here the tax is on suppliers. In this case, total supply and total emissions are endogenous and will typically adjust following a change in public sector production.

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