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Complying with the Kyoto Protocol under Uncertainty: Taxes or Tradable Permits?

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Summary

The Kyoto Protocol on climate change allocates tradable quotas to developed countries, but lets them free to choose the means to respect their quota. There are good reasons for a country not to control its firms through internationally tradable permits. We thus compare a tax and purely domestic tradable permits for the European Union, the U.S and Japan. Information on abatement costs and international permit price is imperfect and stems from nine global models. Permits perform better than a tax for Japan and the U.S., whereas both instruments yield a similar outcome for Europe. Applying Weitzman (1974)'s framework in this new context, we show that these results are due to the positive correlation between costs and benefits: models that predict a low abatement cost in one country generally do so in others too, thereby forecasting a low international permit price.

Keywords: Climate change, uncertainty, policy choice

JEL: D81, Q25, Q28

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1. Introduction[1]

Many observers seem to believe that the Kyoto Protocol to the U.N. Framework Convention on Climate Change requires its Parties to cover their firms by internationally tradable permits. This is doubly false. The Protocol allocates tradable quantitative emission limits to States, but let them free to choose the means to respect this quota: purchase of international permits and credits, command-and-control regulations, implementation of a domestic tradable permit system, carbon taxes… Furthermore, even if a Party chooses to set a domestic tradable permit system, nothing requires that these permits should be exchangeable with other Party's tradable permit schemes, or with Kyoto's permits and credits.

Indeed, there are good reasons for a country Party to the Kyoto Protocol not to generalise internationally tradable permits. For example, the European Commission (2001) directive proposal on CO_2 trading will, if adopted by the Council and the Parliament, create purely European emission allowances whose exchangeability with credits and permits created by the Kyoto Protocol will still have to be decided in another directive (Boemare and Quirion, 2002).

First, from an environmental point of view, the outcome of the Bonn and Marrakech agreements are far weaker than what some negotiating countries, such as the European Union, have been advocating during the negotiation process. In particular, some activities potentially damaging for biodiversity, local environment and local populations will generate credits, such as large-scale tree plantations (FERN, 2001).

Second, for geopolitical reasons, OECD countries may want to control the financial flow towards the ex-USSR that may stem from "hot air" credits. Concerns on the fate of these funds have lead some academics and negotiators to propose an "early crediting" (i.e., prior to 2008) for Joint implementation, and "green investment schemes" (Moe et al., 2001), to target funds from the Kyoto mechanisms towards the modernisation of ex-USSR countries' energy sector. However, the former proposal has been rejected at COP 6, while acceptance of the latter is at the discretion of Russian and Ukrainian governments.

Last, there are sound economic reasons for preferring other instruments. Firstly, a government may prefer to stabilise expectations of domestic agents by fixing either the carbon price or the domestic abatement. This is particularly true in the post-Marrakech context, for if the U.S. do

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not ratify the Kyoto Protocol and if Russia and Ukraine do not exercise monopoly power on the permits market, the equilibrium permit price may well fall to zero. In this context, relying mainly on international permits may mean postponing abatement until after 2012 which is unlikely to be an efficient trajectory, given the technical inertia. Secondly, Copeland and Taylor (2000) show how an international permit trade that is beneficial to both private participants may be detrimental to the buyer or to the seller country, because private firms do not take into account the consequence of their behaviour on terms of trade.

How, then, should a Party to the Kyoto Protocol choose a domestic instrument? Economic literature invites to adopt a tax or tradable permits, because these instruments equalise the marginal abatement cost between sources. To discriminate between taxes and permits, the main strand of literature focuses on the uncertainty on abatement cost, following Weitzman (1974). This line of analysis has already been applied to climate change, e.g. by Pizer (1999), but in order to discriminate between a price instrument (taxes) and a quantity one (quotas) as the basis of an international agreement. However, the choice of a quantity instrument has already been made at the first Conference of the Parties to the UN Climate Convention (COP 1, Bonn, 1995) and reaffirmed in subsequent Conferences of the Parties. Admittedly, a number of academics advocate an international price instrument, or a hybrid regime combining permits with a price cap and a price floor, in the spirit of Roberts and Spence (1976); cf. Hourcade and Ghersi (forthcoming). However, such proposals are very unlikely to be implemented for the first commitment period (2008-2012) of the Protocol.

In the present paper, we show that Weitzman's analysis may also be applied to climate change in a different context: the choice of an instrument by a country which has ratified the Kyoto Protocol and wants to comply with this agreement.

We assess the expected outcome of a price instrument (a tax), a quantity one (non-internationally exchangeable tradable permits), and an virtual "ideal" instrument that would guarantee the realisation of the ex post optimum, as analysed by Ireland (1977). We then discuss the opportunity of internationally exchangeable tradable permits. We provide this analysis for three (groups of) countries: the European Union, Japan and the U.S. Our two main hypothesis are the following.

First, the benefit from reducing emissions is not measured in environmental terms because, as a first approximation, the global emission cap (among developed countries) is fixed by Kyoto. Instead, the benefit from domestic emission abatement is in terms of international permits sold, banked or not bought by the government at the end of Kyoto's first commitment period (2008-2012).

Second, all the information available on abatement costs and permit price (hence marginal benefits from abatement) is taken from nine global models. We use Weyant and Hill (1999)'s reconstruction of marginal cost curves for these models. Uncertainty stems from the (huge) discrepancy between these models as regards forecasted abatement cost and international permit price. We consider only uncertainty among models and disregard the uncertainty within each model. In other words, the authority in each group of country knows that all these models are highly imperfect, but it has no other information source and places a same subjective probability of realisation on each model.

We proceed as follows. In a second section, we present our assumptions in more depth. We then compare the expected net benefit of the price, quantity and "ideal" instruments, on the basis of the non-linear reconstructed marginal cost curves of the nine models (section 3). It turns out that in Japan and the U.S., permits perform better than taxes, despite the flatness of the benefit curve. This contradicts the basic version of Weitzman's model. We thus explain our results by applying various expanded versions of this model, using local linear approximations of our marginal abatement cost curves (section 4). It turns out that the crucial factor is the positive correlation between costs and benefits, which stems from the fact that, except for western Europe, models which predict a low abatement cost curve also forecast a low international permit price. Section 5 concludes.

2. Assumptions

2.1. Definition of benefits

As we already stated, the benefit from reducing domestic emissions is not measured in environmental terms but in term of international quotas that can be sold or that do not have to be bought. This may puzzle an environmental economist, but recall that Weitzman's framework was not specifically developed for environmental purposes. The rationale for our interpretation is that the global emission cap (among developed countries) is fixed by the Kyoto Protocol. As a consequence, and disregarding for the moment the various loopholes in the Kyoto, Bonn and Marrakech agreements, every extra abatement in one country corresponds to less quota import (or more quota export), so it allows less abatement abroad. Quotas may also be banked for future commitment periods, but then again, if future commitment periods are defined soon enough and if expectations are correct, the present marginal benefit from banking quotas is their current price (Helioui, 2002).

2.2. Information on costs and benefits

We use nine global models: AIM, MIT-EPPA, G-cubed, Abare-GTEM, MERGE3, MS-MRT, the Oxford Model, RICE and SGM. We construct proxies of these models' marginal abatement cost curves by a procedure similar to Weyant and Hill (1999) and Hourcade and Ghersi (forthcoming). The 16th Energy Modelling Forum study (hereafter EMF 16) provides, for each of these models, a marginal abatement cost for three configurations of compliance to the Kyoto Protocol: global trade in international permits, trade limited to Annex I countries, no trade[2]. Together with the requirement that zero abatement entails zero cost, this provides us with four (price, quantity) pairs for each model. We then compute least-squares fits to these data as linear combinations of x, x^2 and x^3, x being the abatement[3]. Every curve thus go through every equilibriums computed by the models and available to us[4]. Figure 1 below displays these fitted functions for each region; the large points indicate the intersections between the quota price (assuming global trade) and marginal abatement cost curve, for each model.

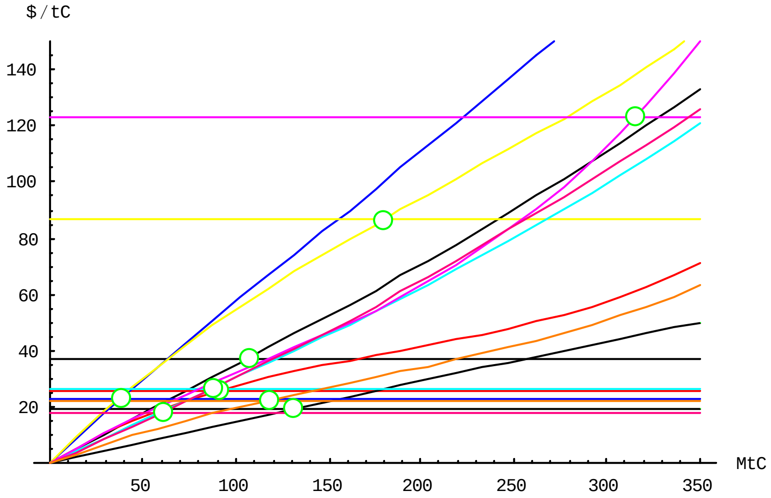
[2] Four other models are included in the EMF study but we have not taken them into account because of a lack of data availability.

[3] All computations have been done with Wolfram Mathematica 4.0. Mathematica notebooks are available from the author upon request.

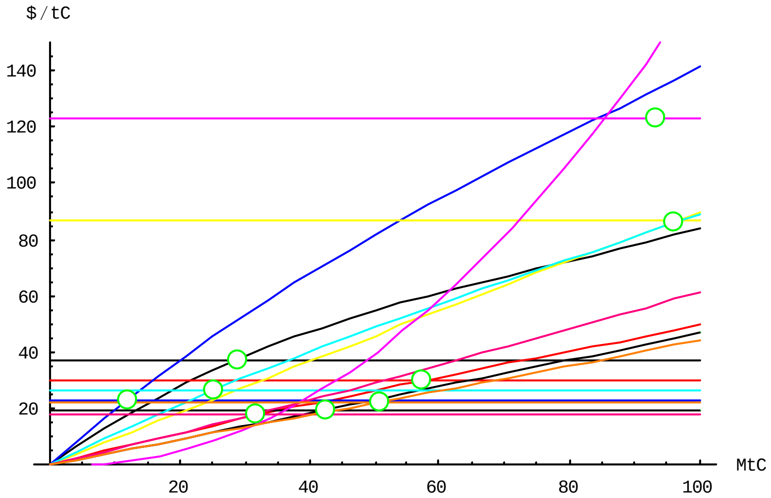
[4] The only computational problem aroused for the Oxford model applied to western Europe: the curve fitted with the usual procedure exhibited a huge negative cost for limited abatement levels. We thus used a linear combination of only x and x^2 in this case.

Figure 1. Reconstructed marginal abatement cost and benefit curves for each model

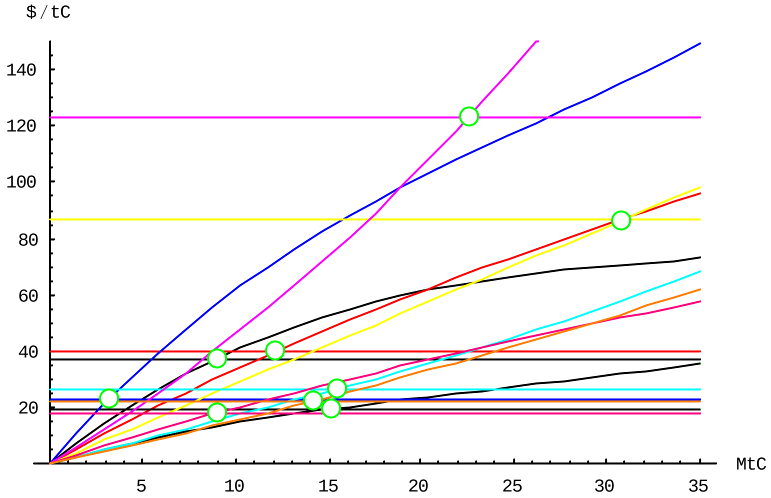
1.a. United States



1.b. Western Europe



1.c. Japan



This procedure is open to some criticisms. First, assuming a domestic marginal abatement cost in one country, independently of what the other countries do, neglects activity relocation driven by international trade in the goods market (Copeland and Taylor, 2000), terms of trade effects and hydrocarbon price feedbacks. Second, most models we use do not include other gases than CO_2, neither carbon sequestration, nor the recent downward revisions of business-as-usual emissions for ex-USSR. As a consequence, they overestimate both costs and benefits. Costs are also overestimated by neglecting local ancillary benefits from emission reductions (in particular the decrease in air pollution). Last, they assume U.S. participation in the Protocol, which is highly unlikely at least as long as the current administration is in place. However, to date, no systematic comparison of models that includes these features is available.

Concerning benefits, we choose the set of prices corresponding to a global trade. This is not because we believe that the Clean Development Mechanism is likely to allow for a significant part of global abatement. However, our models over-estimate the international quota price because of the various factors not included in the modelling exercises and mentioned above: sinks, other gases and revision of baselines. As a consequence, the price ranges corresponding to a global market in the EMF 16 study is much more likely than the one corresponding to an Annex I market.

We provide results on three world regions: Western Europe, the U.S and Japan. Weyant and Hill (1999) also present results for a fourth region, CANZ (Canada, Australia and New-Zealand), but since there is no political coordination between these three countries, providing policy recommendations for this whole region would be of few interest.

2.3. Market power in the quota market

We assume that each country is a price-taker in the quota market, not for the reason that market power is unlikely, but because the simulations reported in Weyant and Hill (1999) do so. However, we will see in the conclusion that accounting for market power would reinforce our results.

2.4. Availability of information

As in Weitzman's model, when we examine the tax and the non-internationally exchangeable tradable permits, we presume that firms know the true abatement cost curve when they make their productive decisions, while the government has only limited information on this curve. Since our model is not dynamic, the government cannot adjust its policy. At the end of Kyoto's first commitment period, when its emissions and the international permit price is known, it buys the international permits required to comply with its commitment (if any). These trade may for example take place during the "additional period for fulfilling commitments" (also known as the "true-up period"), established on this purpose by the Marrakech Accords, which will last one hundred days after the approval of national emission inventories for year 2012.

The ideal price instrument further assumes that firms know the international permits price when they make their productive decisions. To go further would require dynamic abatement cost curves, to take into account inertia in emissions.

2.5. Risk neutrality

As in the rest of post-Weitzman literature, we assume away risk-aversion and simply suppose that the government maximises the expected value of the net benefit of each instrument.

3. Simulations

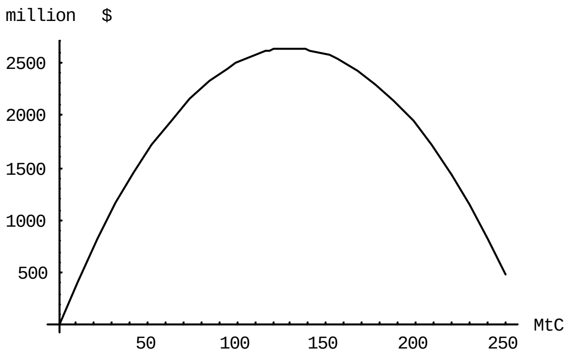
One can easily compute the expected net benefit from a given abatement $\hat{q}$:

$$E\left[\hat{q}\, p_i^* - \int_0^{\hat{q}} MAC_i\left(x\right) dx\right]$$

where $\hat{q}$ is the abatement, $MAC_i\ (x)$ is the marginal cost computed by model i for an abatement x, and p_i^* is the international permit price according to this model. This function admits a unique maximum for each of our three world regions. Figure 2 presents the resulting graph for Europe.

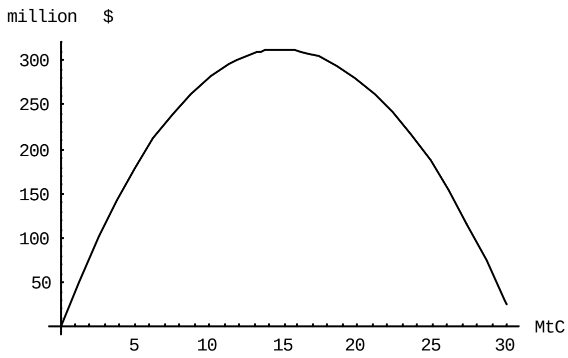
Figure 2. Net expected benefit from a given abatement

2.a. United States



2.b. Western Europe

2.c. Japan



The expected net benefit from a tax is, for a given tax rate $\tilde{p}$:

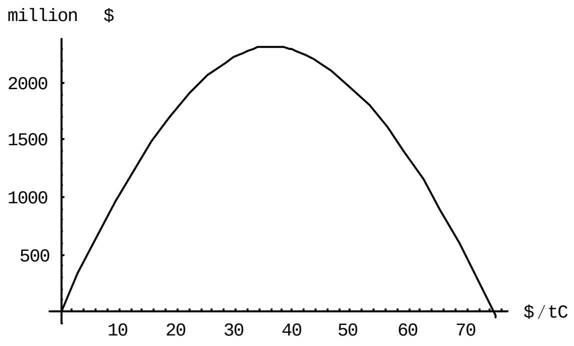
$$E\left[h_i(\tilde{p})\, p_i^* - \int_0^{h_i(\tilde{p})} MAC_i(x)\,dx \right]$$

where $h_i(\tilde{p})$ is the abatement in response to the tax, computed by equalizing the marginal abatement cost to the tax level, for each model *i*.

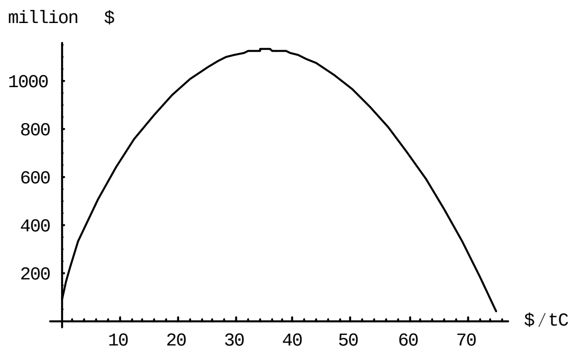
This function also admits a unique maximum. Figure 3 presents the resulting graph for Europe.

Figure 3. Net expected benefit from a given tax

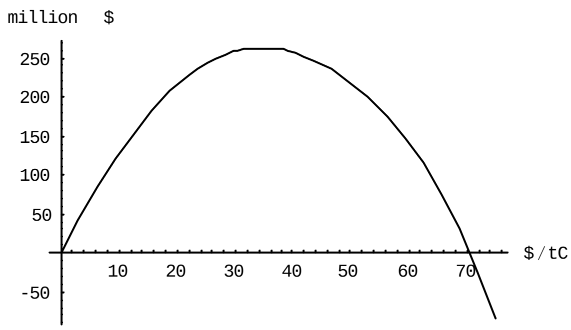
3.a. United States



3.b. Western Europe



3.c. Japan



We then compute the relative advantage of the optimal tax over permits in optimal quantity, i.e., Weitzman's delta. For the U.S. and Japan, the advantage is in favor of permits: by respect, the expected advantage of permits over prices is of 320 and 50 million dollars. In percentage of the optimal permits net benefit, this advantage is respectively of 12% and 16%.

Only in Europe are both instruments roughly equivalent, with an advantage of 22 million dollars (about 2% of the optimal permits net benefit) in favor of the tax.

As a benchmark, it is useful to compute the expected net benefit from an ideal instrument, i.e., which always matches the ex post optimum:

$$E\left[q_i^* \; p_i^* - \int_0^{q_i^*} MAC_i\left(x\right) dx \right]$$

where q_i^* is the abatement predicted by model i in case of global permit trade. Table 1 sums up these results.

Table 1. Optimal level and outcome of our three instruments

	Optimal tax		Optimal permit scheme		Net benefit from the ideal instrument
	Rate (US $\$_{1990}$/ton C)	Net benefit (million $)	abatement (million ton C)	Net benefit (million $)	
U.S.	36	2321	130	2641	4073
W. Europe	35	1129	52	1108	1577
Japan	35	263	15	313	426

The superiority of non-tradable permits over taxes (for the U.S. and Japan) or the rough equality (for western Europe) may puzzle the reader used to Weitzman's basic model, but can be explained by more sophisticated versions of this framework. This is the aim of the next section.

Note that both instruments outcome fall far short of the net benefit of the ideal instrument. The magnitude of the divergence is not surprising given the degree of uncertainty.

4. Explaining our results through a literature review

The formal economic analysis of the choice between a price instrument (i.e., a tax) and a quantity instrument (i.e., a tradable permit scheme) for protecting the environment dates back to Weitzman (1974)'s seminal paper. The author first recalls that, as long as the abatement cost curve is known with certainty, both instruments are equivalent. However, in case of uncertainty on abatement costs, this is no longer the case. To go further, he utilises local linear marginal abatement costs and benefits, approximated around the optimum.

4.1. Weitzman's simplest model

In the simplest model of Weitzman's paper, the marginal abatement cost is[5]:

$$C_q(q,a) = c_1 + a + c_2(q - \hat{q})$$

[5] Following Riedinger (2000), we slightly modify Weitzman's notations by using c_1 instead of C', c_2 instead of C", b_1 instead of B' and b_2 instead of -B".

where q is the abatement, $\hat{q}$ is the optimum, c_1 and c_2 are strictly positive parameters and a is a random variable standardised so that $E[a]=0$. Note that, as stressed by Ireland (1977, p. 185), this literature provides no clue on how to choose the optimum $\hat{q}$. The marginal abatement benefit is:

$$B_q(q,b)=b_1+b-b_2(q-\hat{q})$$

where b_1 and b_2 are strictly positive parameters[6] and b is a random element standardised so that $E[b]=0$. An additional assumption (relaxed later) is that a and b are uncorrelated.

The author then derives the reaction function $h(p)$ by which firms react to a tax p, the optimal tax rate $\tilde{p}$ and the comparative advantage of taxes over permits:

$$\Delta_1 \equiv E\left[B\left(h(\tilde{p})\right)-C\left(h(\tilde{p})\right)\right]-E\left[B(\hat{q})-C(\hat{q})\right]=\frac{s^2}{2c_2^{\ 2}}(c_2-b_2)$$

Where s^2 is the variance of a.

One can see that Δ_1 is positive, i.e., a tax should be preferred, if and only if the marginal abatement cost curve is steeper than the marginal environmental benefit curve ($c_2>b_2$). In our context, because the marginal benefit curve is completely flat ($b_2=0$), Δ_1 is always positive.

However, two footnotes in Weitzman's article, developed further in the subsequent literature, draw a more complex picture.

4.2. Uncertainty on the slopes of the marginal abatement cost and benefit curves

First, there may be an uncertainty on the slopes, not only on the positions, of the marginal abatement cost and benefit curves:

$$C_q(q,a,f)=c_1+a+\frac{c_2}{f}(q-\hat{q}) \qquad (1)$$

$$B_q(q,b,g)=b_1+b-\frac{b_2}{g}(q-\hat{q}) \qquad (2)$$

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[6] Note that all results below remain valid for a downward-slopping marginal benefit curve (b_2 negative) as long as we have $c_2>-b_2$, to avoid a corner solution, i.e., a complete abatement.

where f and g are random variables standardised so that $E[f]=E[g]=1$. Weitzman further assumes that all random variables are uncorrelated.

The comparative advantage of taxes over permits is now:

$$\Delta_2 = \frac{s^2}{2c_2^{\ 2}}\left(c_2 - \left(1+d^2\right)b_2\right)$$

where d^2 is the variance of f. A higher variance generally favours permits over prices, but has no effect in our situation, since we have b_2=0.

4.3. Correlation of the uncertainty on costs and on benefits

If there is a correlation between a and b (but not between the other random variables), we have:

$$\Delta_3 = \frac{s^2}{2c_2^{\ 2}}\left(\left(1-2\frac{s_{BC}}{s^2}\right)c_2 - b_2\right)$$

and with, in addition, uncertainty on the slopes of the two curves:

$$\Delta_4 = \frac{s^2}{2c_2^{\ 2}}\left(\left(1-2\frac{s_{BC}}{s^2}\right)c_2 - \left(1+d^2\right)b_2\right)$$

where s_{BC} is the covariance of a and b. A positive (negative) covariance reduces (increases) the advantage of taxes over permits. Computations by Stavins (1996) suggest that this covariance is more likely to switch the choice from taxes to permits than the other way round. In our context where b_2=0 and c_2>0, the tax is preferred if the correlation between costs and benefits is positive and high enough compared to the variance of the cost, more precisely if and only if:

$$s_{BC} > \frac{s^2}{2} \qquad (3)$$

4.4. Other correlations

With other correlations between the random variables, it becomes very difficult to get clear-cut results. Yohe (1977) graphically studies the effect of the correlation of a and f, neglecting any other correlation. It turns out that a negative (positive) correlation of a and f, i.e., a steeper (flatter) marginal cost curve usually associated with a higher position of this curve, favours permits (taxes). Analytically, the comparative advantage of taxes over permits is now rather complex, even if we assume away the uncertainty on the slope of the benefit curve:

$$\Delta_5 = E\left[\frac{f a^2}{2c_2} + \frac{b_2^2 f^2 a\, s_{fa}}{c_2^2 (b_2 + c_2)} + \frac{b_2 f b\, s_{fa}}{c_2 (b_2 + c_2)} - \frac{b_2 f^2 a^2}{2c_2^2} - \frac{f a b}{c_2}\right] - \frac{b_2^2 \left(c_2 + b_2 (1+d)^2\right) s_{fa}^2}{2c_2^2 (b_2 + c_2)^2}$$

In our context, with b_2=0, we end up with a much simpler expression:

$$\Delta_6 = E\left[\frac{f a^2}{2c_2} - \frac{f a b}{c_2}\right].$$

The first, positive, term reflects the relative slope effect as in paragraph 4.1 and the second, which may be positive or negative, the correlation between costs and benefits as in paragraph 4.3. However, note that both terms are modified by correlations with the slope of the cost curve.

4.5. Explaining the superiority of permits over taxes

Which of the above mentioned mechanisms is able to explain the superiority of domestic permits over the tax? To cast some light on this question, we have computed linear marginal cost and benefit curves around the optimum, chosen as the mean abatement in the global trade scenario[7]. We have then computed the parameters and random variables for equations (1) and (2) above.

Table 2 below presents the "real" comparative advantage of taxes over permits (i.e., based on simulations from section 3) and the various approximations that we have surveyed in paragraphs 4.1 to 4.4.

[7] This is not the true optimum quantity, as computed in the last section, because the genuine cost curves are not linear but third degrees polynomials. However, these optimums differ only by a few per cents.

Table 2. Approximations of the comparative advantage of taxes over permits

(million US $_{90}$)	"*real*" Δ	$\Delta_1 = \Delta_2$	$\Delta_3 = \Delta_4$	$\Delta_5 = \Delta_6$
U.S.	-320	555	-118	-402
Western Europe	22	235	193	-4
Japan	-50	110	-57	-62

The standard formula Δ_1 (which is equal to Δ_2 with our flat benefit curve) which only accounts for the relative slopes naturally concludes to an overwhelming domination of the price instrument and is thus a very bad indicator in our context. Δ_3 (which is equal to Δ_4 with our flat benefit curve) always invites to use the good instrument, although for the U.S. and western Europe it is significantly biased towards the price instrument. Last, Δ_5 (equal to Δ_6 with our flat benefit curve) which takes into account all the relevant correlations, gets closer to the "real" Δ than Δ_3 for the U.S. and western Europe, but not for Japan. The remaining divergence with the "real" Δ is due to the non-linearity of the "real" marginal cost curves.

Overall, it turns out that the dominant effect is by far the positive correlation between costs and benefits, which is high compared to the variance of costs, except for western Europe. In the other two regions, condition (3) above is fulfilled; see table 3 below which displays s_{BC}, the correlation coefficient between the position of the marginal cost curve and that of the marginal benefit curve.

Table 3. "Correlation" effect versus "relative slope" effect

	U.S.	**Western Europe**	**Japan**
s_{BC}	162	28	335
$s^2/2$	134	158	220

This is not surprising: models that are "optimistic", i.e., that predict a relatively low abatement cost curve, in one country, generally do so in other world regions too, thereby forecasting a relatively low international permit price. Note that such a correlation also stands in a less formal decision-making framework: if, say, hybrid cars, wind generators or clean substitutes to fluorinated gases are cheaper than expected at the end of this decade, they will likely drive the marginal abatement cost curves down in all Annex I countries, thus reducing the international permit price. The influence of the positive correlation of benefits and costs is often seen as an interesting but rather academic possibility. In our context, however, it is of the utmost importance.

Last, the correlation between the slope of the marginal cost curve and the position of the benefit cost curve has not been mentioned anywhere in the literature, to our knowledge. However it is quantitatively important in our context, for the U.S. and especially for western Europe: compare Δ_5 to Δ_3 in table 2 above.

5. Conclusions

Although Weitzman's framework for choosing an instrument under uncertainty has been applied by several authors to the choice of an international coordination regime against climate change, it had never been used to choose a domestic instrument for complying with the existing international climate change mitigation regime – the Kyoto Protocol.

Using nine global models as the source of information and uncertainty on abatement cost curves and international permit price, this paper provides the first such analysis.

According to our simulations, a quantity instrument performs better than a price one for complying with the Kyoto Protocol in Japan and the U.S., whereas both instrument yield a similar outcome for western Europe. Such a conclusion is rather welcome since tradable permits are less unpopular than taxes in the U.S, whereas the European Commission is trying both to implement a tradable permit system and to set harmonised minimum excise duties for fossil fuels.

In addition, a survey of the relevant literature has allowed us to identify the mechanism driving these results: the positive correlation between costs and benefits uncertainty. This is not surprising: models that are "optimistic", i.e., that predict a relatively low abatement cost curve, in one country, generally do so in other world regions too, thereby forecasting a relatively low international permit price.

Of course, there are many other reasons, not captured in our framework, for choosing an instrument: ability to drive innovation, institutional constraints, political feasibility… However, the contrasted outcome of price and quantity instruments under uncertainty has been properly identified by economic literature as being a key criterion, and this is especially important given the huge uncertainty that a decision-maker faces in the context of greenhouse gases abatement.

In the future, this work could be extended in three directions.

First, more recent simulations, taking into account other gases than CO_2, carbon sequestration, revised business-as-usual emissions and local ancillary benefits from emission reductions could be used if a systematic comparison in the spirit of Weyant and Hill (1999) were available. Also, consequences of the U.S. withdrawal of the Protocol for the other participants' instrument choice would be worth looking at. On these two points, we will be able to update our analysis when the results of the ongoing Energy Modelling Forum multi-gas working group become available.

Second, we have assumed away market power in the permit market, to stick with the assumptions of the simulations we use. Note that a country having a monopsony power in the international permit market would face a decreasing benefit curve, as more abatement would decrease the equilibrium price. From the standard Weitzman model, this would reinforce the advantage of the quantity over the price instrument, at least if some of the correlations neglected by this model do not lead to a different direction. Other instruments could then perform better than the two single-value instruments we have looked at (the tax and the non-internationally exchangeable permits): a combination of permits, tax and subsidy, in the spirit of Roberts and Spence (1976) and a non-linear price instrument. However, since costs and benefits are positively correlated, the quantity instrument may then again perform better than these non-linear instruments (Shrestha, 2001).

Third, simulations displaying the cost of delaying abatement would allow us to test a potential advantage of internationally tradable permits over other instruments. Indeed if economic agents could wait for the true international permit price to be known before making their productive decisions, internationally tradable permits would perform as well as the contingent price instrument studied above. But obviously, since most greenhouse gases abatement decisions suffer from an important inertia, a delay in abatement would raise the abatement cost curve. However, *some* delay until new information arrives, especially in the most flexible sectors, may be beneficial.

Last, we could drop the assumption of risk-neutrality and use decision criteria that assume some degree of risk-aversion.

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