Tradeable Permits and Climate Change Policy

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Abstract

We survey the literature on tradeable permits (TP) as a tool of global climate change policy. First, we briefly review the scientific evidence and summarize existing international agreements. Then, we review the design of TP programs. Third, we deal with international issues, including modified efficiency conditions, the role of government and private agent trading, trade and the environment, and international political economy.

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1 Introduction

In this paper, we survey the literature on tradeable permits as a tool to mitigate global environmental problems like global climate change. Currently, there exists no survey that deals specifically with this instrument. We aim to provide a comprehensive review of this instrument and its potential use in climate change policy. The second goal of this paper is survey explicitly international aspects of environmental policy, including political economy factors. Thus, this survey is a complement to Kolstad and Toman (2001). The prototype global problem is the global climate change problem, but the arguments developed in the paper can be modified to apply to other topics as well.

We start by discussing the scientific background in section 2.1. Section 2.2 comments on the estimates of benefits and costs. Section 2.3 describes the political and legal background, focusing on the development of the Kyoto Protocol and succeeding agreements. In dealing with environmental problems, there are three central questions that economists can try to answer: "Why?", "When?", and "How?". Section 3.1 therefore starts off with a simple model of externalities and derives the condition for social optimality. A proper understanding of the dynamic dimension of environmental problems is absolutely crucial and we therefore devote a significant amount of discussion to new developments in the theory of the optimal timing of environmental policy (section 3.2). In section 3.3, we look at the three theoretically instruments for environmental policy and compare them along several dimensions.

In section 4, we discuss design issues of tradeable permit programs (like grandfathering versus auctioning of permits) and the theoretical treatment of economic instruments in models of induced technological change. In section 4.2 we review the current usage of emission trading programs in the US and in the world. We also summarize lessons we can learn from these programs and other programs of flexible instruments like taxes. Section 5 considers the international dimension explicitly. The results for emission trading depend on whether only private agents, only governments, or both are allowed to trade. A special section deals with important intersections and mutual influences of domestic and international policies. Section 5.3 considers the relationship between trade and the environment. We also briefly comment on the political economy of international environmental policy in section 5.5. Section 6 concludes.

2 Climate change policy: An overview of issues

2.1 The scientific background

In this section, we summarize the main empirical facts relevant to the object of study. Aside from some substantial results, the major conclusion of this section is that there is significant uncertainty as to the causes and effects of climate change. For space reasons, we cannot go into too much detail here; for such more in-depth analysis see IPCC (2000) and the sources cited in that report.

Uncertainty is a dominant characteristic of environmental externalities, including the accumulation of greenhouse gases leading to climate change. While for some time it was almost heretic for anyone to doubt the strong and negative effect human economic development has on the climate in total, today scientists are beginning to warn against an overly pessimistic attitude. The question of uncertainty also has important consequences for theoretical models which deal with the timing of environmental policy. First, there is uncertainty about future emissions. Ever better and more precise modeling techniques allow us to get a better idea of how emissions will develop in the future. Heil and Selden (2001) provide the most recent estimates, but the sheer number of scenarios estimated for the Mitigation Report of the IPCC, namely 519 (!), indicates that there is tremendous uncertainty both about the business-as-usual and the abatement scenarios.

Second, the consequences of CO_2 emissions and in particular their relation to global climate change are still less well understood. Let us examine a few of the results that have been published. Some of the US National Academy of Science findings from June 2001 are the following: Earth's temperature rose by 0.7F to 1.5F during the 20th century. Most of the warming stems from a rise in concentrations of greenhouse gases, including carbon dioxide. Before the Industrial Revolution, atmospheric carbon dioxide levels were typically 190 to 280 parts per million by volume. They are about 370 ppmv and are rising 1.5 ppmv per year. In these studies it is argued that human activities are responsible for the increase, the primary causes being burning oil, gas, and coal.

While the scientific integrity of this study cannot be doubted, some findings are controversial. For example, some studies find that 70% of the increase in the temperature of the last 100 years happened before 1940. This seems to suggest that there is no connection with motorization etc. Also, one has to bear in mind the relations we are dealing with here: Global carbon dioxide emissions consist of 770 billion tons of natural emissions (43% from the oceans, 28% from the ground, 28% from trees and plants) and 26 billion tons (=3 % of total emissions) of man-made emissions. Furthermore, new analyses in Greenland suggest the possibility that the earth became warmer first which then caused increased CO_2 emissions from the ocean (just like carbonated water emits CO_2 when it gets warmer). This type of reverse causation has not been ruled out by other research (IPCC 2000).

Besides the causes of global warming and climate change, the effects are also controversial. It is plausible that the consequences would include shrinking glaciers, disrupted agriculture, flooded coastal regions, and the increasing likelihood of droughts. Still, there is some disagreement. Table 1, an excerpt from findings presented in IPCC 2000, illustrates some impacts resulting from projected changes in extreme climate events.

TABLE 1 ABOUT HERE

Summarizing, there is no absolute proof that anthropogenic greenhouse gases caused the temperature rise and that this will have very severe effects. In other words, there is benefit uncertainty[1]. However, given the extremely

[1] There is also a second sense in which there is benefit uncertainty: We really don't know to which extent people are aware of the dangers and care about them. The past few years have seen a dramatic increase in interest in the notion of "happiness" as an operationalized concept of utility. Despite concerns about the relevance and rigor of this concept, it has turned out to be quite robust (see Frey and Stutzer (2001) for a survey of the current literature). It appears feasible to test whether happiness, as measured, e.g., from the World Values Surveys, when controlling for the deciles of income, demographic

high stakes of the issue, it is important for researchers and policy-makers to be aware of options in different scenarios. It does not mean, however, that given the uncertainty, we should in any case act now (Gollier, Jullien and Treich 2000). Therefore, the so-called "Precautionary Principle", which emerged in the mid-1980s as a clause in international treaties such as the Conference of Rio on Environment and Development, may be problematic if it is not carefully used. Rather, this study assumes that human-made CO_2-emissions may make a substantial contribution to climate change and that this change may be associated with severe negative effects on mankind. Then, if we decide to act (under the conditions derived in the framework of the optimal timing of environmental policy), we can consider the different instruments in more detail.

Uncertainty is further exacerbated when we take technological change into account. Indeed, the relationship between technological change and the environment is one of the most contentious issues. It is a commonplace argument that since technological change goes hand in hand with economic development, this will generally lead to a deterioration of environmental quality. However, this argument neglects both the question of

characteristics, and institutional differences, is affected by environmental quality in general and CO_2 concentrations in particular. For first thoughts in this direction, see Wagner (2002b).

whether higher income actually is bad or good for the environment and possible improvements in technology over time. Chakravorty and Roumasset (1997), for example, develop a model of global warming with endogenous substitution of energy resources. The key result of their paper is that, if historical rates of cost reduction in the production of solar energy are maintained, most of the world's coal will never be used. Thus, the estimates of the IPCC may be much too high. Again, this brings us back to the issue of uncertainty developed in the beginning.

Finally, uncertainty about the costs of environmental policy is pervasive (For example, consider the calculations by Ciorba, Lanza and Pauli (2001) for the European Union). There are many far-reaching aspects involved, for example the environmental Kuznets curve, i.e. a suspected non-linear relationship between income levels and pollution (Bradford, Schlieckert and Shore 2000, Harbaugh, Levinson and Wilson 2000), but this is not the place to go into details concerning these issues.

2.2 Costs and Benefits of Climate Change Risk Mitigation

Responding effectively to climate change risks requires us to consider the potential costs and benefits of various actions as well as inaction. How their impacts are assessed is what differentiates different approaches from another. We will briefly review concepts of cost-effectiveness and efficiency below. Here we consider some other topics (Shogren and Toman 2000).

Long-term equity and fairness A key element of climate change policy is that it goes beyond one single generation. Indeed, a core issue in the discussion is that of fairness towards future generations (see Portney and Weyant, eds (1999) for a number of papers on the subject). The "sustainability" argument enters the stage often as well. There are also advocates of more aggressive GHG abatement. They assert that conventional discounting may be inequitable to future generations by leaving them with unacceptable climate damages or high costs from the need to abate future emissions very quickly (Howarth 1996, Howarth 1998). On the other hand, supporters of the conventional approach argue that any evaluation of costs and benefits over time that understates the opportunity cost of foregone investment is a bad bargain for future generations, since it distorts the distribution of investment resources over time (Schelling 1995, Weitzman 1999).

Influences on the benefits Shogren and Toman (2000) list factors that have impacts on the benefits. These factors include:

- potential scale and timing of damages avoided. Generally, the effects in developing countries are presumed to be worse than in the developed world (IPCC 2000).

- assumptions about adaptation: Some critics of the earlier IPCC estimates argue that damages likely will be lower than predicted because expected temperature increases from a doubling of atmospheric GHG concentrations probably will be less than projected, ecosystems seem to be more resilient over the long term than the estimates suggest, human being can adapt more than was supposed, and damages are not likely to increase proportionally with GDO (Mendelsohn 1999).

- catastrophic risks: When damage costs are not only uncertain but also involve a chance of a catastrophe, there is a rationale of more aggressive early actions to reduce GHG concentrations. There is an ongoing discussion as to how large the risk has indeed to be in order to rationalize near-term actions as aggressive as those envisioned in the Kyoto Protocol (Nordhaus 1994, Peck and Teisberg 1993, Peck and Teisberg 1996, Pizer 1999).

- irreversibility of GHG emissions: As we will discuss below in the section on optimal timing, because GHG emissions persist in the atmosphere for centuries, the resulting long-term damages strengthen the rationale for early and aggressive GHG control (Narrain and Fisher

1999).

- ancillary effects: Climate change policy has potential positive side effects on water quality. These effects remain fairly uncertain in magnitude (Lutter and Shogren 1999).

Influences on the costs Hugely differing cost estimates (Weyant and Hill 1999) typically reflect different views about three key assumptions:

- Stringency of the abatement policy
- Flexibility of policy instruments
- Possibilities for development and diffusion of new technologies

These factors will show up more than once in the discussion below, so we leave them without further comment here.

Summary Benefits and costs must be considered in the context of the uncertainties that surround climate change. As our brief review shows, economic analysis provides a relatively strong rationale of pursuing only gradual abatement of GHG emissions. Because damages accrue gradually, catastrophes are uncertain and off in the future, and unit mitigation costs are likely to fall over time, it makes sense to proceed gradually.

We have not said anything about the instruments with which we want to tackle the climate change problem. In order to understand instrument choice best, in section 3 we briefly review key issues of available environmental policies in an abstract setting, before we turn to special issues related to international environmental policy.

2.3 The political and legal background

The following table lists the milestones in international climate change policy. Summaries of these steps are also provided elsewhere (e.g. Rosenzweig et al. 2002). Despite its problems, clearly the most important step was the the Kyoto Protocol. To become binding, it requires ratification by 55 countries who make up 55% of the world's CO_2 emissions. The European Union ratified the Kyoto Protocol on May 31, 2002, submitting its ratification instruments to the United Nations. EU Member States.Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom completed their domestic ratification processes in time for the EU deadline. The EU aimed for the May 31 deadline in order to make possible entry into force of the Kyoto Protocol by the World Summit on Sustainable Development in Johannesburg in August. Entry into force, however, is dependent on ratification by Japan and Russia to meet the required minimum representation of 55% of Annex I (developed) countries' 1990 CO2 emissions by ratifying Parties. In May 2002, Japan voiced its intention to also ratify the Protocol.

What's important in the context of the present survey is that it allows for both formal GHG trading among the Annex I developed countries and bilateral trading through the Clean Development Mechanism (CDM). Under the CDM, emissions reduction activities in noncapped, non-Annex I nations can generate emission reduction credits for Annex I nations. Annex I trading could involve tying together domestic emissions trading programs or a project-level approach in which participants can generate emission credits from emission-reducing actions in other Annex I countries (so-called joint implementation). These projects can be organized and financed by Annex I investors, the developing countries themselves, and international third parties. There are several obstacles to achieving the goals of the CDM, namely low-cost emissions reductions for developed countries and tangible benefits to the host country. The key question is how to design a credible monitoring and enforcement system that does not impose such high transaction costs that it chokes off CDM trades (Goldemberg 1998, Haites and Yamin forthcoming, Jepma and Gaast 1999).

After the initial Kyoto protocol, the parties have realized the many details that need to be taken care of in an international climate change accord. For example, the agreements of Marrakech alone - while certainly not the most ambitious - take up 245 pages[2]. They mainly concern operating rules of the flexible mechanisms of the Kyoto protocol, rules defining a party's eligibility to participate in the mechanisms, and procedures and modalities for the compliance process. Another important agreement in Marrakech was that the Russian Federation has received the increased sinks tonnage that it wanted to be part of a deal. However, despite important technical details concerning the compliance process and the implementation of CDM and JI projects, the big issues countries now fact are discussions on the adequacy of commitments and future commitment periods. A key point also is whether re-engaging the US is a necessary condition for continuing in the framework. In spring 2001, the US had announced that it was not intending to ratify the Kyoto Protocol (for a summary of the development of that process see Shogren and Toman (2000)). While there are strong opinions on both sides of the argument (for an overview see IETA 2001, 2002a), "hard facts" from an actual empirical study are missing and await future research. For details on what happened in Marrakech, see Schneider and Wagner (2002a). Table

[2] They mainly concern operating rules of the flexible mechanisms of the Kyoto protocol, rules defining a party's eligibility to participate in the mechanisms, and procedures and modalities for the compliance process. For details see Natsource (2002).

2 summarizes the most important milestones so far.

TABLE 2 ABOUT HERE

Despite some progresses in the international arena, most recently, it appears to be the case that countries' own initiatives are superseding or at least improving upon the hopes that had developed out of the Kyoto Protocol and its follow-up accords. Countries like the UK and Denmark have made significant progress in establishing CO_2 emission trading programs; in fact, on April 2, 2002, the UK emission trading scheme went into action.

When one tries to evaluate the recent international steps, one has to go back to the original provisions of the Kyoto Protocol. While only history will be able to show an ultimate judgement of the achievements and problems of this agreement, many economists have argued that in essence the Protocol does "too little too fast." Instead of "narrow but deep" approach taken so far - focusing on bringing in a relatively small number of core countries and look for a commitment of those countries to reduce emissions markedly -, it has been suggested that a better way forward would be a "broad but shallow" approach in the short run, together with clearly specified tightening of requirements over time (Stavins 2002).

3 Key issues in environmental policy

3.1 Why? Internalizing externalities

3.1.1 A simple microeconomic model with externalities.

The starting point of almost any kind of environmental policy debate is whether and to which extent there exist externalities that merit policy attention. Although this point is well-known it is useful to restate the relevant problem. Suppose the utility of a group of individuals is given by $U = U(X, Q)$, where $X = X(I, E, Q)$ is production and $Q = Q(E)$ is pollution. E stands for emissions in the course of the production of X. I are conventional inputs. Assume $U_X > 0, U_Q < 0, X_I > 0, X_E > 0, X_Q < 0, Q_E > 0$. The condition of a pareto-efficient allocation is

$$U_X X_E + U_X X_Q Q_E + U_Q Q_E = 0 \tag{1}$$

or

$$X_E = \frac{U_Q Q_E}{U_X} - X_Q Q_E \tag{2}$$

Thus, production should be expanded up to the point where the marginal product of emitting one unit more equals the marginal damage the additional emissions impose on the consumers' utility and on the producers. By contrast, firms in a competitive market would continue producing until $X_E = 0$. Then, the level of pollution is too high - there is a negative externality.

This survey deals with economic policy instruments to internalize these externalities. Of course, there is also the property rights approach, which regards the failure of the market in the case of externalities as stemming from a failure to define exclusive property rights (Coase 1960, Dales 1968). In the presence of transaction costs and in public good cases, the simple assigning of property rights might not work; the Coase Theorem also has several other conditions, including the absence of income or endowment effects and the absence of third-party impacts. The Coase Theorem is a statement about the achievement of the cost-effective allocation of control responsibility. In addition, in the presence of uncertainty, pareto optimality is generally not attained in a competitive equilibrium (see Weitzman (1974)).

3.1.2 Ethical considerations

Economists often take the presumption that flexible instruments can be used to deal with environmental problems as given. However, we also - at least briefly - need to address ethical concerns. Kelman (1981) criticizes utilitarianism and comes to the conclusion that some acts whose costs are greater than their benefits may be morally right. Second, he maintains that pricing the environment - as must be done for cost-benefit analyses of any kind - inherently decreases its perceived value (p. 362). We think that Robert Solow best summarized what can be said about Kelman's arguments: The article is profoundly, and not entirely innocently, misleading (Solow 1981). At worst, there can be errors of technique, but no errors of principle. Also, Kelman does not recognize that, since the benefits and costs of a policy decision are usually enjoyed and incurred by different people, a distributional judgement has to be made which can override any simple-minded netting out.

3.2 When? The optimal timing of environmental policy

3.2.1 Overview: Understanding environmental risks

When should society adopt a (costly) policy to reduce emissions (of CO_2, for example)? The standard approach of using cost-benefit analysis essentially does not answer this question incorrectly; it *ignores* it completely. A certain measure is recommended if the present value of the expected flow of benefits exceeds the present value of the expected flow of costs. However, this approach overlooks three central characteristics of most environmental problems: i) Uncertainty about costs and benefits; there is both economic and ecological uncertainty. ii) Irreversibilities with respect to damage and to costs of implementing policy. On the one hand, policies aimed at reducing ecological damage impose sunk costs on society (discrete investments in the form of higher abatement requirements etc.). On the other hand, environmental damage can be partially or totally irreversible. A certain environmental policy thus may have sunk benefits also. iii) Delay of action is possible. Policy adoption is not a now or never proposition. Rather, it is truly a question of "When?"

The theory required to deal with these characteristics has been developed in the context of financial and option theory. It is not a simple theory - it involves stochastic processes and differential equations. However, these methods are required to adequately deal with the challenges of environmental problems and researchers cannot afford to ignore them in favor of easier methods, which often give incorrect results. A number of recent studies have begun to examine the implications of irreversibility and uncertainty for environmental policy, and some of them have made use of the theory of irreversible investment decisions (Arrow and Fisher 1974, Chao 1995, Kolstad 1992, Pindyck 2000, Abel, Dixit, Eberly and Pindyck 1995, Dixit and Pindyck 1998, Dixit, Pindyck and Sodal 1997, Hassett and Metcalf 1994). The basic insights can be gained from a simple model (Pindyck 2001) whose setup and solution we present. For technical details we refer the reader to the sources just cited, and in particular to Pindyck's paper[3].

3.2.2 An optimal stopping problem

This model is stylized, but it shows some of the key results the theory of dynamic programming has to contribute to environmental economics. Let S be a state variable that summarizes the stock of environmental pollutants, e.g. the average concentration of CO_2 in the atmosphere. Let X be emissions, that is the flow variable that contributes to S. Suppose that S follows an arithmetic Brownian motion (see Dixit and Pindyck (1993) for an introduction to this concept).

$$dS = (\beta X - \delta S)\, dt + \sigma_S dz_S \tag{3}$$

Further we assume that the flow of social cost associated with is described by

[3] There are many other issues which we cannot deal in detail with here. One interesting question is how to model gradual policy changes. Another question is how to allow for (subjective) perceptions of risk (Slovic 1987).

$$B\left(S_t, \theta_t\right) = -\theta S^2 \tag{4}$$

where θ shifts stochastically over time according to the geometric Brownian motion

$$d\theta = \alpha \theta dt + \sigma_\theta dz_\theta \tag{5}$$

θ stands for changes in tastes and technologies. For simplicity, and because there is no a priori reason not to, we assume $E_t\left(d\sigma_S d\sigma_\theta\right) = 0$ where E_t is the expectations operator.

Pindyck further assumes that the policy we think about implementing consists of reducing emissions from X_0 to zero at a sunk cost of $K = kX_0$. The goal is to maximize

$$V = E_0 \int_0^\infty B\left(S_t, \theta_t\right) e^{-rt} dt - E_0 K\left(E_1\right) e^{-r\hat{T}} \tag{6}$$

where $\hat{T}$ is the time at which the policy is adopted.

This is an optimal stopping problem. The solution requires finding a threshold level $\theta^* (S)$ that plays the role of a cutoff rule: When $\theta \geq \theta^*$, the policy should be adopted. Clearly, we expect $\theta^* (S)$to be decreasing in S. Through using the tools of dynamic programming, Pindyck (2001) finds the cutoff value

$$\theta^* (S) = \frac{\gamma (r - \alpha)^3 K}{2 (\gamma - 1) \beta X_0 [(r - \alpha) S + \beta X_0]} \tag{7}$$

β is an increasing function of σ. Two core results of the model are noteworthy: First, higher uncertainty induces longer optimal waiting. In a graph that draws the optimal $\theta^* (S)$ for any given S, we would see that the schedule is downward sloping, indicating the fact that the higher the stock of emissions, the lower the option value of waiting (because the costs of waiting are high). However, if one of the two variances increases, uncertainty increases, and the schedule shifts up, increasing $\theta^* (S)$, and thus making it worthwile to wait longer.

Secondly, we need to consider that there are two opposite irreversibilities: On the one hand the economic costs associated with environmental policy are often irreversible (both discrete investments and expenditure flows can fulfill this criterion). On the other hand, the environmental damage due to increases GHG concentrations is longterm and thus totally are partly irreversible. Thus, the option value of waiting (due to the sunk costs) must be balanced against the benefit of early action (due to sunk benefits). The implications of the model are best understood with a numerical analysis. Following the numbers in Pindyck (2001), assume: $r = 0.04$, $\beta = 1$, $E_0 = 300,000$ tons/year. Set the present value of the cost of policy adoption at $K = \$4$ billion, which presumes that much of the actual cost is reversible. Also use $\sigma_1 = 0.2$ and $\sigma_2 = 1,000,000$. This means that, first, the social cost generated by the pollutant stock has a 20 percent annual standard deviation, and a 200 percent standard deviation for a 100-year time horizon. Second, after 100 years, this implies a standard deviation of 10 million tons for the stock level.

Pindyck finds that under these quite reasonable assumptions, the value of waiting is large. The underlying intuition is that ecological irreversibility does have an effect, but at the levels of uncertainty characterizing environmental issues, usually not enough to overcome the higher threshold due to benefit uncertainty. Stochastic fluctuations in the pollutant stock, which are assumed to be arithmetic in nature, create uncertainty about the future social cost of continued emissions only because the benefit function $B(\theta, M)$ is quadratic in M. By contrast, stochastic fluctuations in θ shift the entire social benefit function for every level of M.

According to the traditional decision rule, a policy should be adopted when the net present value of it exceeds its cost, i.e. when the ratio of NPV / Cost is greater than one. By contrast, given the above values, the NPV/Cost at the optimal threshold that was endogenously determined is usually far greater than 1. This is in particular true for small values of S, since then continued emissions make a big difference for uncertainty over future values of S, because they contribute a lot in percentage terms to the expectations of those future values.

So, after all, it may not be heretic for an economist to argue that hastily implemented environmental policy can do more harm than good. However, one should not try to take the arguments developed in this section is basis for a permanent delay in action. There *is* an optimal time of action. The challenge for future theoretical modeling is to improve our models to the extent that policy can really rely on them.

3.3 How? The theory

This chapter presents the main results of the classic theory of environmental policy. Any survey must cover these results; but they are kept relatively short, because the results are well-known. We focus on uniformly dispersed pollutants like CO_2. With non-uniformly dispersed pollutants like SO_2, the conditions are more complicated. At times, when not too much simplicity is lost we present the case for such pollutants as well, because it allows us to think about differential economic impacts or differential impacts on actual well-being.

We start the discussion by considering criteria we would like "good" environmental policy to fulfill.

3.3.1 Criteria

Environmental efficacy Laymen and laywomen typically assume that the improvement or conservation of environmental quality as such is the overriding goal of environmental policy. It often surprises them to learn that economists do not think so. Indeed for a long time, the primary objective of environmental policy has rather been the achievement of acceptable levels of emissions, depositions, or ambient concentrations at the lowest possible cost. Still, environmental efficacy is an important criterion to judge the success of any environmental policy. It goes without saying that large uncertainties are associated with any such assessment.

Cost effectiveness The standard result is that in order to have a cost-effective solution, you need equalization of marginal abatement costs. This can be easily seen in a static setting (consider Tietenberg (1985), for example). The environmental goal, the available technology are fixed. The total level of emissions is the sum of all emissions (E_t) minus reductions per source (R_t) plus any natural or background emissions. We want to minimize costs of reductions such that total emissions are less than or equal to the desired level of emissions E^0. But we consider also accumulation. Since with CO_2, environmental damage is - if at all - caused by the stock of accumulated emissions over time and not by the flow of emissions at one specific point in time (barring extreme emissions), the program thus is

$$\min \sum_{t=1}^{T} \sum_{i} \frac{C_i\left(R_{i,t}\right)}{\left(1+\delta\right)^{t-1}} \tag{8}$$

$$s.t.\ N + \sum_{t=1}^{T} \sum_{i} \left(\bar{E}_i - R_i\right) \leq E_t^0 \text{ for all t} \tag{9}$$

Under the assumption of a convex cost function, the program has a well-defined interior solution, namely

$$\frac{\partial C_i\left(R_{i,t}\right)}{\partial R_{i,t}} = \left(1+\delta\right) \frac{\partial C_i\left(R_{i,t-1}\right)}{\partial R_{i,t-1}}, \text{ for all } i \tag{10}$$

meaning that marginal abatement costs must increase over time at a rate equal to one plus the rate of time preference. At the same time, the marginal costs per unit of emission control for every source must be equal at each point in time. The question then is, how can economic instruments help us attain this solution. We can only mention that with non-linear interactions between pollutants, the Kuhn-Tucker conditions may not be representative of the cost-minimum because the second-order quasi-convexity condition of the constraint function is violated. For more on this, see Endres (1986), Zylicz (1994), Klaasen (1996).

Already at this point, let us note, however, that especially in the international realm where we have countries at vastly different stages of development, the optimality condition may be different. We will discuss the findings of Chichilnisky and Heal (1994) in more detail in section 4 of the survey.

Administrative practicability Non-trivial information requirements are associated with any kind of environmental policy that aims to be cost-effective. An emission inventory is needed, and depending on the instrument cost function information is also necessary. In principle, no information on costs is required for an emission trading system to be both environmentally effective and cost efficient.

The implementation, monitoring, and enforcement costs are relatively hard to assess. Emission charges face costs because the charge revenues must be collected. Regulation might require costly legal procedures. Emission trading requires the environmental agency to keep track of the trades that take place and to compare the emission rights possessed with actual emissions. A related point is that most environmental policy instruments, whether conventional or market-based, can be directed to one of a range of levels of regulatory intervention: inputs (e.g. a lead tax), emissions (e.g. an emission tax), ambient concentrations, exposure, and risk or damages. Administrative costs increase as one moves further alon this set of points of intervention, but it is also likely that the instrument is then more clearly addressing the "real" problem. More on the distinct administrative costs of each instrument can be found in Klink et al. (1989), Bohm and Russell (1985), Harford (1978) and Keeler (1991).

Political economy aspects Since this survey mainly focuses on the international aspects of environmental policy, the question of how to actually make environmental policy such that it is politically feasible and can be carried out by a large number of allies merits particular attention. We will return in much more detail below to a survey of recent research on the question of international environmental policy. There is, however, also a large tradition focusing on domestic environmental policy and the political economy of that policy area (Kirchgaessner and Schneider 2003, Schneider and Volkert 1999, Keohane, Revesz and Stavins 2000) and we refer the reader to these papers for surveys of the political economy of environmental policy. They typically employ a political market metaphor and provide arguments for why both firms and regulators often prefer command and control instruments. Hockenstein, Stavins and Whitehead (2001) provide an additional reason for why businesses are often not enthusiastic about market-based instruments. They argue that they fear most that the rules will change.

The overall conclusion of much on the literature is that economic incentives might face disadvantages compared to command-and-control approaches, with the exception, perhaps, of grandfathered permits. In spite of their cost efficiency advantages, they increase expenditure for industry. In addition, both the regulatory authorities and industry might prefer regulation because it gives them more power.

We only mention one line of research that seems particularly fruitful for future inquiry. Already early on, Buchanan and Tullock (1975) had suggested that the industry might prefer emission standards to charges because they result in higher profits. Standards act as a barrier to entry for new firms, thus raising profits for existing ones, whereas charges or emission standards prer unit of output do not preclude entry. Hahn (1990) identifies two basic interest groups: industry and environmentalists. Since recently the political economy of special interest politics has made significant progress in formal modeling, it would be interesting to explore the role of interest groups as discussed recently by Grossman and Helpman (2001) to learn more about their theoretical and empirical role in environmental policy.

Dynamic efficiency The relation between environmental policy and technological change is very difficult to assess. We discuss it in a little bit more detail below and therefore do not deal with it further here. We refer the reader to the excellent survey by Stavins (2002).

3.3.2 Instruments for environmental protection: Overview

Command-and-control (CAC) instruments It is hardly necessary to describe the workings of direct regulation (CAC). It comes in different forms: performance standards, regulation of variables correlated with emissions, design standards, and bans on products or processes. It should not be forgotten that regulation is a fast and often less expensive way to temporarily control sudden emission peaks. But in general, without sufficient information on marginal control costs, regulation is likely to be inefficient when marginal costs differ between polluters (Newell and Stavins 1999). This is especially true when control options are discontinuous. DeClerq (1983) and Forsund (1992), as well as Klaassen (1996) provide additional overviews of these issues.

Incentive-based (market-based) instruments: Taxes and permits

The second big group concerns instruments which aim to impose *economic* constraints and use the power of self-interested behavior to improve environmental quality. Common features of economic instruments include i) the existence of financial stimuli, ii) the possibility of voluntary action, iii) the involvement of government authorities, and iv) the intention to maintain or improve environmental quality (Opschoor and Vos 1989).

Thus, it is the first two characteristics that set them apart from regulatory approaches to environmental policy. The two main instruments are emission charges ("green taxes", "Pigou-taxes") and tradable emission permits.

To illustrate how the two instruments work, let us go back to the static case with non-accumulating pollutants to show how emission charges and tradable permits allow the policy-maker to in principle attain the cost-minimum. The ideas that follow are very accessibly presented in Baumol and Oates (1979), Baumol and Oates (1988), Bohm and Russell (1985), Griffin (1987) and OECD (1991).

For emission charges, the case is straightforward. Under the assumption that each source minimizes costs, imposition of a uniform charge per unit of emissions leads to the following problem for each firm.

$$\min C_i\left(R_i\right)+T\left(E_i-R_i\right) \tag{11}$$

The solution has $C_i' = T$. Since the charge is uniform, the marginal costs for each source are equal, which is exactly the condition for a cost-efficient solution. Note, however, that if pollution control costs are not fully known with certainty, a trial-and-error procedure is needed to reach the desired level of emissions. In other words, environmental effectiveness is not guaranteed. This goal is also in danger in the presence of technological indivisibilities (Rose-Ackermann 1973). In a dynamic setting and with economic growth, charges must be adapted. The literature on the reaction of investment to volatility in taxation shows that such maybe unsystematic adapation can lead to distortionary and adverse effects.

A trading system for emission permits is in principle designed in the following way. An emission permit is defined in terms of an allowable emission rate per year. The total number of emissions is determined and the certificates are distributed to the firms as endowments W_i either by grandfathering or auction (see below). Facing the market for permits where there exists a price P for the permit, each firm solves

$$\min C_i(R_i) + P(E_i - R_i - W_i) \tag{12}$$

Clearly, the cost minimum is achieved if marginal costs of emission reduction equal the price of the permit, $C_i' = P$. Under perfect market conditions, there is one price, leading to equal marginal costs for all producers - voila. In a sense, tradable permits work under an institution of Coasian bargaining.

Under uncertainty, the efficiency of price-based (tax) systems compared with quantity -based (permit) systems depends on the properties of costs and benefits. If uncertainty about marginal abatement costs is significant, and if MC are quite flat and marginal benefits of abatement fall relatively quickly, then a quantity instrument will be more efficient than a price instrument (Weitzman 1974). The key point is that whether or not welfare losses under an emission charge exceed those under a tradable permit system depends on the steepness of both the cost and damage functions. If the damage function is relatively inelastic, a small change in emissions results in considerable welfare losses and quantitative controls are preferable. If the cost function is relatively inelastic, emission charges are the appropriate instrument. However, it is conceivable that in a dynamic setting, things might look different. Future research needs to clarify what the conditions look like in a context with uncertainties, irreversibilities and the option to wait with policy. It seems possible that Weitzman's conditions need to be modified but they retain their basic intuition. Furthermore, Stavins (1996) shows that when there is also uncertainty about marginal benefits, and benefit uncertainty is positively correlated with marginal costs, there is an additional argument for quantity instruments, even though price instruments might still be preferable When the optimal stock level rises over time, however, price instruments may be favored (Newell and Pizer 2000).

3.3.3 Summary: Criteria and conditions for successful implementation

There is a wide consensus among economists that generally market-based instruments are preferable to regulatory instruments, because they allow the attainment of the least-cost solution with less information requirements. This is all the more important the more heterogeneous the firms are with respect to their abatement costs. For example, it has been shown that cost-savings of market-based policies relative to uniform performance standards increase in a straightforward manner as a function of greater abatement-cost heterogeneity (Newell and Stavins 1999) .

More generally, one can compare instruments by asking the following questions: Do they achieve stated goals/standards? Are they cost-effective? (For CAC, the answer is typically in the negative) Do they provide the government with information it needs? What are the monitoring and enforcement possibilities? (We will come back to this below). Are they flexible in the face of change (in tastes, technology, or resource use?) Do they provide dynamic incentives for research, development, adoption, and diffusion of better pollution-control technologies? Do they contribute to an equitable distribution of economic and environmental impacts? Is the purpose and nature of the policy understandable to the general public? Is the policy feasible in terms of enactment and implementation?

We can summarize the discussion in the previous sections answering some of the questions just posed in the following table 3 (Klaassen 1996). As a preview of some of the design issues to be discussed later, we also present the table 4 from Klaassen (1996) that summarizes conditions that have an effect on cost efficiency and environmental effectiveness of economic instruments.

Since we do not discuss taxes in detail, we refer the reader to Klaassen's excellent summary of these points.

TABLE 3 ABOUT HERE

TABLE 4 ABOUT HERE

Table 4 is quite self-explanatory, so let us only briefly explain one example of how to read it. In the presence of imperfect enforcement, practically all instruments suffer with respect to environmental effectiveness (explaining the "-" in the relevant row of the table). Some charge systems may get around the problem by providing incentives for correct reporting of emissions (explaining the "0/-" evaluation). The cost-efficiency of charges is not affected, whereas that of permits is negatively affected by imperfect enforcement. The impact of imperfect enforcement on regulation is unknown. More generally, the "?" signs in the table indicate potentially fruitful areas for future research.

4 Permit trading and environmental finance

4.1 Important design issues for emission trading in general

The goal of this chapter is to review briefly the main results of the most important policy-relevant aspects of permit trading. The idea is to outline those issues that arise independent of an international or national context.

4.1.1 At what level should trading be established?

A principal design issue that is sometimes overlooked in more detailed discussions is at which level permits should be established. In principle, we would want to regulate risks and impacts. However, it is quite difficult to establish a system of tradable risk permits. This is why policy typically moves one or two steps away from this level, leading to either *emission* permit trading or *input* permt trading. A true CO_2 trading program would correspond to the first type; a carbon (content) trading program belongs to the second group. In general, the choice between the two depends on the degree of uniform mixing of the pollutant. For example, it would be problematic to have a sulfur-content trading program because SO_2 is a highly non-uniformly mixed pollutant - which is why the US has chosen to implement an SO_2 allowance trading program. Aside from this physical property, there is also an economic or political aspect: administrative feasibility. Clearly, the closer to the actual impacts regulation takes place, the more complex it gets. Taken together, these two factors suggest an important trade-off. For greenhouse gases, the relatively uniformly-mixed nature and the complexities of the international negotiations suggest that a carbon trading program is more likely to succeed. Indeed, most suggestions contain such a program in order to *indirectly* lead to a reduction in CO_2 emissions through the reduction of carbon content. In the following, we focus on issues that arise with any kind of tradable permit program.

4.1.2 Initial allocation; Grandfathering versus auction

The practice and political economy The initial allocation of emission permits is a contentious issue. As a fact, we note that almost all emission trading programs in action have started with grandfathered permits. For example, the most important emission trading program so far, the Clean Air Act amendments of 1990 dealing with SO_2 trading provide for annual auctions in addition to grandfathering - but such auctions involve less than three percent of the total allocation. Overall, the auctions have proven to be a trivial part of the overall program (Joskow, Schmalensee and Bailey 1996). This is astounding since on the theoretical level, there seem to be compelling reasons for auctioned permits.

Economic reasons for auctioning permits First of all, with perfect information and no transaction costs, trading will result in the economicially efficient outcome independently of the initial distribution of permits (Montgomery 1972). Second, auctions are more cost-effective in the presence of certain kinds of transaction costs (Stavins 1995). Third, the revenue raised can be used to reduce other distortions (Goulder and Bovenberg 1996). Note also that while instruments such as tradeable permits can create entry barriers that raise product prices, reduce the real wage, and exacerbate preexisting labor supply distortions, this effect can be offset if the government auctions the permits, retains the scarcity rents, and recycles the revenue by reducing distortionary labor taxes. Fourth, auctions provide greater incentives for firms to develop substitutes (see the section on technological progress). Fifth, due to the revenue raised by auctions, administrative agencies may have a bigger incentive to monitor compliance (Ackermann and Stewart 1985). Finally, grandfathering can lead unregulated firms to increase their emissions in order to maximize the pollution rights that they obtain if there is a transition to a market-based system (Dewees 1983). Overall, under almost any circumstances to be encountered in the real world, an auction of emission rights is preferable to grandfathering.

4.1.3 Incentives for technological innovation

Jaffe, Newell and Stavins (2000) summarize the literature on the effects of market-based instruments on technological progress. A simple model, in whose framework most of the discussion can take place, is suggested by Kerr and Newell (2001). Consider a world of complete certainty. Suppose a new technology becomes available to each firm, and for each firm the technology comes at a different cost, $\mathrm{C}(Z_t, t)$, that depends on firm-specific characteristics Z_t (a vector). Let Π_0 denote profit before technology adoption, and let Π_1 denote profit after technology adoption. The optimization problem then is to choose an optimal time for adoption T:

$$\max_T \int_0^T \Pi_0\left(Z_t, R_t, K_t, t\right) e^{-rt} dt + \int_T^\infty \Pi_1\left(Z_t, R_t, K_t, t\right) e^{-rt} dt \qquad (13)$$

where K_t is the stock of capacity of the new technology already installed in the industry (to allow for the so-called stock effect), R_t represents the stringency and form of regulation faced by each refinery, and r is the discount rate. The no-arbitrage condition says that each firm will choose to adopt as soon as

$$\Pi_1\left(\cdot, T\right) - \Pi_0\left(\cdot, T\right) - rC\left(Z_T, T\right) + \partial C\left(Z_T, T\right)/\partial t \geq 0 \qquad (14)$$

and as long as adoption is profitable

$$\int_T^{\infty} [\Pi_1(\cdot) - \Pi_0(\cdot)]\, e^{-rt} dt - C(Z_T, T)\, e^{-rT} > 0 \tag{15}$$

Clearly, firms with the highest value of adoption will tend to adopt first, later firms will come in as costs fall or benefits (e.g. because of higher regulatory stringency) rise (= rank effect).

Thus, the model suggests that firms will gradually adopt the technology as its costs fall and increased regulatory stringency increases the value of adoption. The tradeable permit system encourages all plants to take action until their marginal costs equal the permit price. Sellers of permits, i.e. those with MC<permit price, adopt the new technology to make even higher profits, and vice versa. Thus, the tradable permit system provides incentives for more efficient adoption, but it can lower incentives for adoption for some plants with high compliance costs.

Kerr and Newell show that for petroleum refineries, increased stringency encouraged technology adoption. Importantly, the tradable permit system provided incentives for more efficient adoption decisions. The study is important because it is one of the first to truly empirically test the diffusion process. Further studies in other areas are needed. Further research is also needed to further examine the effect of uncertainty in this field .In particular, the above formulation ignores irreversibilities, so that the optimal timing issue becomes somewhat too simple because the additional option value of waiting is ignored.

What about differences within the realm of market-based instruments? Again, we refer to the Jaffe et al. (2000) survey for a comprehensive overview of the literature. Two additional recent papers merit mentioning. Fischer et al. (1998) use a new classification of effects to provide a ranking of policy instruments in terms of their ability to provide the optimal level of innovation. As can be seen in the following table 5, generally, market-based instruments encourage innovation through the abatement costs effect, but discourage it throught the imitiation and the adoption price effects. A recent paper by Zhao (2001) combines the irreversible investment framework with the question of choice between the two market-based instruments. He finds that under fairly general conditions tradable permits are preferred because they maintain investment incentives under uncertainty. Research is by far not complete on this point, however.

TABLE 5 ABOUT HERE

In practice, suffice it to say that they find that the empirical evidence to date is generally consistent with theoretical findings that market-based instruments for environmental protection are likely to have significantly greater positive impacts over time than command-and-control approaches on the invention, innovation and diffusion of desirable, environmentally-friendly technologies. Also, these studies show that the response of technological change to relevant price changes can be surprisingly swift. This is important, since the conventional view differs from this (cf. also the Portney (2001)-report on the CAFÉ program in the U.S., where it is argued that any change in the program would only have very-long term effects anyway).

Another question is whether taxes or emission trading systems lead to more incentives for technological innovation. Albrecht (2000), for example, argues that in a system with grandfathering, companies have much less incentives to promote technology adoption than under a tax system, because they have to bear higher costs. Indeed, this is consistent with the technology adoption model just described. However, this analysis overlooks many aspects that work in the different direction. Economic growth, gradual depreciation of emission permits etc. all go towards rather higher incentives with permits. Also, since we have just shown that grandfathering is not encouraged for other reasons anyways, in a first-best emission permit trading system, there will be an auction - and that is more expensive for the companies.

Future research should clarify which implications also hold in the presence of the considerable uncertainties associated with technology and environmental damages and policy.

4.1.4 Market power and the design of emission permit markets

In order for cost minimization gains to be fully realized, the emission trading market must work in a competitive manner. As indicated above, if some agents have the capacity to influence the transaction price of traded permits or can prevent the entrance of competitors by hoarding permits, efficiency losses may ensue (OECD 2001). For example, Hahn (1984) shows that the deviation of abatement costs from the cost minimum is related to the extent to which the initial distribution of permits differs from the equilibrium distribution (and to the price elasticity of demand).

Another type of strategic behavior occurs if firms use the permit market to drive up rivals' costs (exclusionary manipulation). Note first that this can only occur if firms operating in the same industry also participate in the same permit market. Misiolek and Elder (1989) conclude that, surprisingly, this may not necessarily have a negative impact on cost efficiency. Again, it is unclear to what extent this result survives the inclusion of uncertainty.

A related topic that also has direct policy and design relevance is the problem of transaction costs (Stavins 1995). Suppose transaction costs are a function G of the volume traded. Then, each firm faces the following problem (the other variables are the same as above):

$$\min C\left(R_i\right)+P\left(E_i-R_i-W_i\right)+G\left(E_i-R_i-W\right) \tag{16}$$

Clearly, the interior solution has $C_i'+G'-P=0$. In other words, we now have that marginal pollution control costs will be equal to the permit price minus marginal transaction costs. This restricts the volume of permits traded, depending on which form exactly the transaction costs take. The key implication of Stavins' paper is that the presence of certain forms of transaction costs may also imply that the final equilibrium, and hence cost efficiency, is no longer independent of the initial distribution of permits.

Finally, we point to a topic which is not really related to market power of a firm, but rather to the question of the leverage of the instrument as such: imperfect enforcement. Malik (1990) demonstrates that with imperfect compliance, firms set the level of emissions such that marginal profits equal the permit price plus the expected fine. It would be an interesting exercise to use dynamic programming theory to derive the explicit conditions under uncertainty. Keeler (1991) shows that if the marginal penalty of noncompliance is constant, tradable emission permits lead to less noncompliance than does regulation. With increasing marginal penalties (as a function of the violation), all firms will comply if the permit price below the expected per unit violation penalty. With decreasing marginal penalties, firms that decide not to comply will pollute more than under regulation. In sum, with imperfect enforcement, whether or not tradable permits meet the environmental goal depends on the structure of the penalty function.

4.1.5 Enforcement and management framework

As Chichilnisky and Heal (2000) point out, there are two aspects to an enforcement framework: One is the monitoring of compliance with the regulatory framework and detecting violations. The other is responding to violations in a way that ensures that it is always in the interests of participants to comply. The first aspect clearly is the simpler of the two. As pointed out above, for CO_2, since it is a mostly uniformly mixed pollutant, we do not have to monitor each and every source of CO_2 emissions, but can focus on the sales of the major distributors of carbon-based fuels. In fact, just from such sources, estimates of the consumption of various carbon-based fuels in each country are already available from data on production, import, export, and inventories. It should be noted that if the lives of quotas are not synchronized - if they specify a total of emissions over a multiyear life - matters could be more difficult.

The enforcement posed much more serious problems, in particular in the international context to which we will return below. From the perspective of research, it appears that further insights can be gained - also in terms of valuable policy advice - by inquiring into the contractual relationships between principals (environmental agencies) and agents (firms). In other words, an optimal permit trading program also involves a large part of effective mechanism design that needs to take incentive compatibility constraints into account.

With respect to market management more generally, the clear recommendation from economic theory is to allow market participants to fully exploit cost-saving opportunities and risk-management possibilities, for example through the use of derivatives (as they are already traded in the SO_2 and NOx allowance markets in the US, for example, see Wagner (2002)). In addition to facilitating heding price risks, derivatives also help achieve market depth and liquididy and so improve market functioning.

4.2 How? The practice

4.2.1 Overview

Over the past decade tradeable permit systems have been adopted in a variety of places. There are two basic distinctions: Under credit programs, credits are assigned (created) when a source reduces emissions below the level required by existing, source-specific limits. Under a cap-and-trade system, an allowable overall level of pollution is established and allocate among firms in the form of permits, which can be freely exchanged among sources. A comprehensive summary of the current practice of flexible instruments is Stavins (2000), from whose survey article we summarize some illustrative aspects. Table 6 provides an overview of tradable permit systems. It contains both baseline-and-credit as well as cap-and-trade programs, both of which types we discuss briefly in turn.

TABLE 6 ABOUT HERE

4.2.2 Baseline-and-credit

Under this kind of programs, credits are assigned when a source reduces emissions below the level required by the existing, source-specific limits. These credits can enable the same or another firm to meet its control target.

As described in the introduction, the countries that had ratified the Framework Convention on Climate Change (FCCC) decided in 1995 to establish a pilot phase for "activities implemented jointly" (AIJ). In these cases, industrialized nations or firms within those nations can finance projects in other countries to reduce net emissions of GHG and thereby attempt to meet their own GHG commitments. Note that this is different from "joint implementation", which refers to the prospective use of project-level credits among industrialized countries, each of which has targets under the Kyoto Protocol.

A number of countries have established such national AIJ programs. For example, the U.S. Initiative on Joint Implementation, established in 1993, approved 22 projects through 1997. Other specific examples of AIJ projects include a Norway-Mexico co-financing arrangement for a lighting project in Guadalajara and Monterrey and a project switching a district heating plant in Decin, Czech Republic, from coal to natural gas, with financing from several U.S. electric utilities. Jepma (1999), Woerdman and Gaast (1999) and Dixon (1999) provide references on more such projects. These programmes are, however, no true emission credit programs, because the investing firm or nation receives no actual credit. Nevertheless, these projects may turn out to be important precursors of a true emission trading program under the Kyoto Protocol.

4.2.3 Cap-and-trade

Arguably the most important application of this type of instrument is the tradable permit system in the US that regulated SO_2 emissions, the primary precursor of acid rain. There are recent papers summarizing the workings of this system (Burtraw and Mansur 1999, Carlson, Burtraw, Cropper and Palmer 2000, Joskow, Schmalensee and Bailey 1998), so we just mention that a robust market of bilateral SO_2 permit trading has emerged, resulting in cost savings on the order of $1 billion annually, compared with the costs under some command-and-control regulatory alternatives. Recent research has focused on applying financial economics tools to analyzing this market. For example, Wagner (2002) applies the theory of storage and an equilibrium model of the forward market to investigate the efficiency of the term structure of vintages under the SO_2 program. Trading levels have increased significantly over time, in particular after Phase II was started in January 2000, bringing almost all electric power generating units into the system. Interestingly, neither have state regulatory authorities hampered trading in order to protect their domestic coal industries (Bailey 1996), nor has the small permit auction market caused problems. The allowance trading program has apparently had very positive welfare effects, due mainly to positive human health impacts and not to the ecological impacts of reduced long-distance transport. While the results is positive, this is different from what was assumed at the time of the program's enactment in1990.

In January 1994, a tradable permit program was launched in a four-county area in southern California to reduced nitrogen oxide and sulfur dioxide emissions in the Los Angeles area (RECLAIM). As of June 1996, 353 participants had traded more than 100,000 tons of NOx and SO_2 emissions (Brotzman 1996). The program is theoretically interesting because it allows no trades from downwind to upwind sources. In other words, this comes close to an ambient trading program.

A market in tradable permits was used in the United States to help comply with the Montreal Protocol, an international agreement aimed at slowing the rate of stratospheric ozone depletion (Hahn and Garthland 1989). If a firm wishes to produce a given amount of CFC, it must have an allowance to do so, calculated on a basis which recognizes the fact that different types of CFCs are likely to have different effects on Ozon depletion. Through mid-1991, there were 34 participants in the market and 80 trades. Unfortunately, no studies of cost-savings were undertaken. In any case, the timetable for the phaseout of CFCs was subsequently accelerated, and a tax on CFCs was introduced, which may have become the binding, i.e. effective, instrument. In Europe, between 1991 and 1994, there were 19 transfers, accounting for 13 percent of the EU's allowable production of ozone-depleting substances (ODS). Other countries that have operated a tradable permit system for ODS include Singapore and Canada.

In 1999, twelve northeastern states and D.C. implemented a regional NOx cap-and-trade system to reduce compliance costs with the Ozone Transport Commission regulations of 1990. The Environmental Protection Agency distributes NOx allowances to each state, and states then allocate allowances to sources in their jurisdictions in a grandfathered manner, depending on 1990 emissions. Farrell, Carter and Raufer (1999) have estimated compliance cost savings to 40-47 percent for the period 1999-2003, compared to a base case of command-and-control regulation. Many of the states in this system also established in-state trading programs in order to meet their statewide caps, as have Michigan and Illinois.

The international experience is rather small. Since 1991, Chile has had an auctioning system in place for bus licenses (Huber, Ruitenbeck and Motta 1998). While actual emission reductions have not been measured, traffic congestion has apparently been reduced by these measures. Chile has also implemented a tradable permit system for total suspended particulates from stationary sources in the Santiage area. Emissions have decreased since the establishment of this program in 1995, but the volume of emissions trading has been low (Montero and Sanchez 1999).

European national authorities have increased flexibility. For example, in Denmark, the Ministry of the Environment fixes annual emissions ceilings in the power generation industry, and leaves the actual allocation to the country's two power plant consortia. The UK allowed intra-firm trading of SO_2-allowances among large combustion plants from 1991 to 1997. But inter-firm trading was not allowed (Sorrell 1999). The system in the Netherlands, where electric power producers face emissions standards for SO_2 and NOx but can comply through cost-sharing arrangements whereby plants with higher abatement costs are compensated, has resulted in intra-firm trading (Klaassen and Nentjes 1997). Finally, in Germany, the transfer of emission reduction obligations among firms in air quality non-attainment areas is allowed. The cost-savings have been estimated to be very limited (Schaerer 1994).

The most recent experiment with market-based instruments is the UK Emission Trading Scheme, aimed at achieving the UK's commitment under the - yet to be ratified - Kyoto Protocol. Schneider and Wagner (2002b) describe the program in detail. Since the first auction only took place in

March 2002, and trading has been somewhat limited so far, it is too early to make an assessement concerning the success of the program.

4.3 Lessons learnt

The first lesson to take away - also looking at other market-based instruments for environmental protection (Stavins 2000b, Stavins 1998) - is that market-based instruments can achieve major cost-savings while accomplishing their environmental objectives.

Taking together the theoretical considerations of section 3.1 and the practical experiences described in section 3.2, the following lessons emerge as conclusions (see also table 7 for a brief summary).

1. It is important that they should be designed to allow for a broad set of compliance alternatives: Banking, for example, was a key element in the success of SO_2 trading in the US. Only this can really induce technological change. The possibility for parties in a permit trading system to be able to create the trades they need to most cost-effectively fulfill their obligations is similarly important[4].

2. Transparency and simplicity - where possible - are paramount. Un-

[4] As mentioned above, an active derivatives market has developed on the SO2 market. According to industry experts, a large part of the gains from trade comes from activity on these markets.

certainty with respect to the rules can clearly have a negative effect on investment, especially within a framework where investment is irreversible. This can also help firms organize better internally to deal with such instruments. Many firms are better equipped to deal with traditional command-and-control approaches.

3. One should use absolute baselines, not relative ones, as the point of departure. This is also important to avoid "paper trades" (Montero 1999) .

4. Monitoring and enforcement are strictly necessary. The standard literature on the question to which extent a trade-off between probability of catching "cheating" and fines exists applies here (see Viscusi and Zeckhauser 1979, Polinsky and Shavell 1979).

5. Free allocation in the beginning should be avoided wherever politically feasible.

6. As economic theory would suggest, where the cost of abating pollution differs widely among sources, a market-based system is likely to have greater gains.

7. Tradable permits will work best if transaction costs are low. It appears that the absence of formal exchanges has not hindered parties in the

SO_2 allowance trading program in the US to benefit from the existence of the market. However, transparency of the market for permits is paramount in order to allow efficient price discovery. Similar caveats apply for other factors that affect the effectiveness of instruments (see the discussion in the text).

TABLE 7 ABOUT HERE

5 International aspects of emission trading programs

5.1 Overview

In this section, we focus on the international context. First, we reconsider the conditions for social efficiency, i.e. a pareto-optimal allocation of emissions (and, conversely, emission reductions). The discussion there takes place around the question to which extent we should pay attention to the result obtained by Chichilnisky and other scholars, namely that equalization of marginal costs of abatement is the criterion for Pareto optimality only under specific conditions. Second, we survey the literature on the relationship between trade and the environment. This brief survey is included here because it is a priori conceivable that trade alleviates or even solves global environmental problems - after all efficiency gains from trade are abundant in other areas. Third, we focus on specific issues associated with emissions trading in the international context. Fourth, we survey the literature that tries to make sense of the political economy of international environmental policy.

5.2 Efficiency conditions revisited

In an earlier chapter, we showed how efficiency requires the equalization of marginal abatement costs across sources. Under the assumption that marginal abatement costs are lower in developing countries, this implies that those countries should have been the first to abate.

However, Chichilnisky (1993) and Chichilnisky and Heal (1994), in unfortunately relatively little noted contributions, point out that the presumption that equal marginal abatement costs are the correct condition for efficiency is not strictly correct. The reason for this is that, simply, a dollar to a person in the developing world does not have the same welfare implications as a dollar to a developed world person. What matters are the real opportunity costs. Formally, the authors find that Pareto efficiency requires that the marginal cost of abatement in each country must be inversely related to that country's marginal valuation for the private good. This has strong policy implications: If richer countries have a lower marginal valuation of the private good, then at a Pareto-efficient allocation, they should have a larger marginal cost of abatement than the lower-income countries. With diminishing returns to abatement, this implies that they should push abatement further. Summarizing, the allocation of property rights in a tradable permit system is important if environmental quality has a direct impact on wellbeing and marginal valuations of private goods differ strongly across countries.

5.3 Trade and environment

We start with a brief a review of the current knowledge on the relation between trade and environment[5] for two reasons. First, it serves to understand better the political economy of international environmental policy. After all, one key determinant of resistance to environmental policy on the international level comes from the uncertain distributional effects for countries. Second, recall a main tenet of trade theory: Free trade maximizes the

[5]We do not discuss the related question of "linkage", i.e. the question to which extent trade policies and environmental policies should be linked (cf. (Bhagwati 2000) and the papers that discuss his contribution).

efficiency of resorce allocation by channeling economic activities to least-cost producers. The point is, however, that if there are market failures - such as unaccounted for externalities or unpriced or underpriced resources -, resources are misallocated to start with and removal of barriers to trade may exacerbate this misallocation. Thus, the net effect is a priori unclear.

5.3.1 Is trade good or bad for the environment?

Many empirical studies have inquired into this question, some with more, some with less involved econometric techniques (see Antweiler et al. (1998) for a good review). Some studies set out to compare efficiency gains from trade liberalization with the costs of increased environmental degradation or needed additional environmental protection measures. For example, Repetto (1993) finds that the gains amount to betwen 1-2 percent of GDP (3-4% for economies with severe distortions) and the damages range from 1-2 percent of GDP to 3-5% of GDP in countries with lax environmental policies. In other words, the evidence here is inconclusive. Other work like studies on growth and pollution levels often add openness as an additional explanatory variable (see Grossman and Krueger (1995), Shafik (1994), Seldon and Song (1994), Dean (1998)). Overall, the results from these studies are best described as mixed. There is very little evidence linking liberalized trade in general with significant changes in the environment.

The main reason why it appears difficult to make sense of the results is that despite many different theoretical approaches, we still lack a unified framework to understand all the effects. Even though there is a rich literature that derives conditions under which trade liberalization is bad for the environment (Chichilnisky 1994, Copeland and Taylor 1994), not always are all possible channels explored fully. The overall direction of the effect depends on the model-specific assumptions, and it is necessary to distinguish several trade-related environmental effects (see table 8, see Panayotou (2000)).

TABLE 8 ABOUT HERE

Scale effects can lead to negative effects when increased trade leads to more pollution without compensating product, technology or policy developments, and to positive effects otherwise.

Structural effects result in changes in the patterns of economic activity and may exert positive environmental effects (e.g. reducing produciton of crops that rely on chemical intensive methods) or negative effects.

Income effects typically lead to positive effects through an increased willingness to pay due to the higher incomes brought about by growth-induced trade (although this is also not a completely clear channel, see Frankel and Romer (1999)). The vast literature on the environmental Kuznets curve has not reached a final conclusion. A recent paper on the subject is by Antweiler, Copeland and Taylor (1998). They develop a theoretical model to divide trade's impact on pollution into scale, technique and composition effects and then look at data on sulfur dioxide concentrations. Combining the different effects and modeling their interplay, they arrive at the conclusion that freer trade appears to be good for the environment from this perspective. Their model is reasonably general to allow its use for other pollutants as well, and we expect to see more work on this in the future. Unfortunately, some have interpreted findings of a nonlinear relationship between income and environmental degradation as a "growing up" problem which can be overcome by rapid economic growth instead of environmental policy. But this interpretation is flawed in several respects: First, it ignores the role of market and policy failures in determining the level of environmental damage cost per additional unit of GDP, and the scope for policy reform to reduce it. Second, it ignores threshold effects and the risk of irreversible environmental damages were environmental degradation to cross such thresholds before reaching the turning point. In particular, current income level of developing countries are nowhere close to the turning point, hence environment-intensive production would continue for a long time, resulting in significant and possibly irreversible environmental damage.

Product effects may go either way: On the one hand, there may be more trade in goods the are beneficial to the environment (like biodegradable containers), on the other hand negative effects from waste-dumping and the like are possible.

Technology effects may involve the spreading of dirty technologies but also the reduction of pollution per unit of product.

Finally, *regulatory effects* through improved environmental policies in response to economic growth from trade work against possible relaxation of environmental polcies because of specific trade pressures or restrictions on environmental policy by trade agreements.

Overall, while the literature has made much progress in highlighting specific channels one at a time, we lack a more comprehensive understanding of the relationship between trade and the environment. One important way forward appears to involve using imperfect competition models a la Krugman (for a model in this direction see Kennedy (1994)).

5.3.2 Environmental regulation and trade

The other causal direction goes from environmental regulation to trade. Do regulations act as barriers to trade? Are differences in abatement costs significant determinants of trade flows? Multilateral trade rules make a fundamental distinction between product standards and process and production methods. Clearly, only the former are candidates for harmonization (see Adams (1997) and Panayotou (2000)). The early literature had focused on income differences or policy differences across countries to show how these drive pollution intensive industries to the lax regulation or low-income country (McGuire 1982, Pethig 1976, Siebert 1980).

But their results may be a highly misleading guide to policy in a world where environmental protection responds endogenously to changing conditions. Also, this earlier work ignored the potential role factor abundance could play in determining trade patterns. In contrast, Antweiler et al. (1998) implement this important extension. Accordingly, the empirical literature typically finds that differences in environmental standards have had very limitied effects on trade patterns. Another reason for this is that environmental control costs are a very small fraction of production costs. In one of the earliest studies on the subject, Walter (1973) found that environmental control costs amounted to 1.75% of the total value of US exports and 1.52% of US imports. Low (1992) found that the traditionally lenient environmental standards in Mexico did not result in specialization in dirty industries (see also Grossman and Krueger (1995)).

A related literature has evolved on the question of how and to what extent foreign direct investment is driven by environmental policy concerns. This literature draws heavily on insights from studies on the importance of environmental regulations to plant location (see Levinson 1997 for a survey). On the international level, repeated tests of the "pollution haven" hypothesis failed to find evidence of a systematic tendency of manufacturing plants to be located in countries with lax environmental standards. Wheeler and Mody (1992) find that multinational firms base their investment decisions primarily on labor costs and market access, while corporate tax rates and, by extension, environmental control costs play little or no role. Also, Repetto (1995) shows that, to the extent that "greener" countries seem to be exporting their "dirty" industries, they predominantly send them to each other, not to developing countries with weaker regulations. In 1995, only 5 percent of US direct investment in developing countries was in pollution-intensive sectors, compared to 24 percent in developed countries with equally stringent (compared to the US) environmental regulations.

5.4 Permit trading on the international level

This section is dedicated to a discussion of design issues and properties of emission trading programs at the international level, in particular for CO_2 abatement.

We first discuss the ability of emission trading to improve upon unregulated outcomes in terms of cost-efficiency. Second, we return to the question of permit allocations.

5.4.1 Cost efficiency

It is our interpretation of the events happening in the recent past that an agreement *that* certain reductions of CO_2 emissions have to be effected is much easier to obtain than an agreement on what is the most cost-effective way to implement it. Therefore, it is important to understand how the use of emission trading can improve *in terms of cost-efficiency* upon the outcome that is obtained without any instruments. Thus, we proceed in two steps here, following closely Klaassen (1996).

1. We derive non-cooperative and cooperative Nash equilibria. These are the benchmark cases.
2. We discuss whether emission permit trading can help to improve upon these outcomes. We treat both the "simpler" case of carbon emissions and the more general case of non-uniformly dispersed pollutants.

Step 1: Benchmark results. Let us consider a simple model which is general enough to extend to non-uniformly dispersed pollutants. Most insights can be gained from the three-country case. Decisions on environmental policies are made by national governments whose preferences are assumed to be representable by the separable form

$$U_i = B_i(Z_i) - C_i(R_i) \tag{17}$$

with $i = 1, 2, 3$ where

$$Z_i = a_{i1}R_1 + a_{i2}R_2 + a_{i3}R_3 \tag{18}$$

and R_i are the emissions reductions of country i, with $C_i(R_i)$ being the associated cost. $B_i(Z_i)$ are the benefits country i gets from overall emissions reductions Z_i. Note that as mentioned this specification applies for non-uniformly dispersed pollutants as well, because then the three a_i's are not equal. In the case of a global pollutant like CO_2, however, we just have that $Z_i = \sum R_i$ for all i.

We now consider different outcomes. The first benchmark case is of course the *non-cooperative Nash equilibrium*, where each country pursues its national interest by maximizing utility s.t. $Z_i = a_{i1}R_1 + a_{i2}R_2 + a_{i3}R_3$. As is well known (Barrett 1990, McMillan 1986, Nentjes 1994), each country reduces its emissions to the point where marginal costs are equal to marginal domestic environmental benefits.

Clearly, countries can improve welfare by coordinating their pollution control policies, if that is feasible. In particular, in a *cooperative Nash equilibrium*, countries maximize the net benefits of coordination subject to the condition that welfare levels are at least as high for every country as they are in the non-cooperative Nash equilibrium. For example, for country 1, the first-order condition now is

$$C_1' = a_{11}B_1' + a_{21}\mu_2 B_2' + a_{31}\mu_3 B_3' \tag{19}$$

where the μ's are the Lagrange multipliers on the utility constraints of country 2 and 3, respectively. Clearly, this first-order condition implies higher reduction levels.

There is a special case of this condition which occurs when all μ's are 1. This situation corresponds to the *full cooperative solution*, where each country chooses R_i so that it maximizes the net benefits of pollution control for all countries, including itself. It is possible to show that the full cooperative solution can be realized as a Pareto-efficient solution for a case where countries apply money transfers in addition to reciprocal emission reductions (Nentjes 1994). In other words, even a cooperative Nash equilibrium in terms of reciprocal reductions generally leaves room for additional gains in net benefits for parties by allowing re-contracting using the commitments to reciprovally control emissions as a starting point. In such a second phase, obligations to reduce emissions are exchanged for money.

Summarizing, agreements taking the form of a cooperative Nash equilibrium of reciprocal reductions of emissions are generally not cost efficient. Thus, the question is whether permit trading programs can improve upon this.

Step 2: Results under emission trading.

In this section, we assume that countries have made an initial agreement on national emission reductions. Each country is allocated emission permits on the basis of this initial agreement. Permits are freely bought and sold between all countries (under the condition that the sume of emissions remains the same). Each permit allows emission of one unit, irrespective of the location. This is both sensible for CO_2, and it reflects the reality of the systems under consideration.

A distinction that needs to be made is whether countries themselves trade, or whether they decentralize decisions and allocate permits to individual firms that trade. Let us assume that if countries trade, they maximize the net benefits of emission reductions plus the net revenues of permit sales subject to the condition that the emissions remaining after abatement do not exceed the number of permits they possess. Assuming that countries only care about the impact of their own emission reduction on environmental benefits and ignore the possible repercussions of trade on the emissions of the other countries, the first-order condition is

$$C_1' = a_{11}B_1' + P \tag{20}$$

i.e. a country reduces emissions to the point where the net marginal costs equal the permit price. One can close and solve the model by considering the excess demand and supply functions. For the case of three countries, market equilibrium is obtained where

$$C_1' - a_{11}B_1' = C_2' - a_{22}B_2' = C_3' - a_{33}B_3' \tag{21}$$

In other words, the result would be equivalent to the case of central international planning if countries were to neglect the impact of their abatement on national benefits, i.e. if countries were to individually behave as cost minimizers. And clearly, the result is equivalent if the benefits in any country are dependent only on the total level of emission reduction - which is just the case for CO_2, for example.

If firms trade, one can assume that they minimize costs and ignore externalities imposed in the form of higher (or lower) deposition on all countries. With a perfect market, we would obtain

$$C_i' = P \tag{22}$$

but this in itself does not imply a Pareto-dominant change in the allocation of emissions. As Klaassen (1996) shows, a Pareto-dominant change does occur again when depositions in each country are independent of which of the countries emit.

Summarizing, emission permit trading in general improves cost-effectiveness over the Nash equilibrium outcomes. However, the real problem is imperfect enforcement. As Maeler (1993), Bohm (1994) and Keeler (1991) argue, in this case, agents might emit more than they are permitted in order to save costs and permit outlays. If countries trade, this noncompliance is restricted, because if they emit more than permitted they also lose domestic benefits. Again, this issue is related to the literature on optimal control and fines.

5.4.2 Allocation of permits

In the introductory section of this chapter, we have mentioned the controversial finding by Chichilnisky, Heal and others that the equalization of marginal abatement costs is not the correct condition for efficiency for privately produced public goods in general, and for those cases where marginal valuations of private goods differ strongly (such as in the international context) in particular. The main policy implication for the design of efficient permit trading programs concerns the allocation of rights.

Assuming that they are not auctioned (which is a safe assumption in the international political economy context), the question remains how they should be distributed. The punchline of the Chichilnisky, Heal, and others research is that equity and efficiency are closely connected, and that we cannot just allocate the permits somehow and then invoke the first welfare theorem. Eyckmans, Proost and Schokkaert (1993) and later Chichilnisky and Heal (2000) show that typically, the initial distribution of property rights or emission permits does determine whether a competitive global CO_2 permit market will operate efficiently. In their view, even after choosing to go with tradable permits as the environmental policy instrument, we need to carefully use the degree of freedom left in terms of the the distribution of property rights. Chichilnisky et al. (2000) concentrate on the first welfare theorem in markets in which agents trade, at a uniform price (that is, not at personalized Lindahl prices), permits to produce privately produced public goods. They take the total quantity of permits fixed by the government at a level consistent with Pareto efficiency. They show that the equilibria are nevertheless generally inefficient, due to the public good character of one of the traded goods. But the main surprise is that there exist certain allocations of rights to emit from which the market overcomes the "free rider" problem and achieves efficiency. This is a key characteristic of competitive markets for privately produced public goods. Heal (2000), Heal and Lin (2000) and Prat (2000), all in the same volume, essentially confirm the robustness of this result.

To our knowledge, no attempt has been made in the literature to interpret the agreements in the Kyoto protocol within this context or to make the theoretical findings operational and turn them into actual policy recommendations. In any case, it is surprising that the academic literature has generally chosen to ignore these aspects. Whenever politicians bring up equity issues, economists are quick to point out that those have nothing to do with efficiency. For once it seems that politicians are right, if not in their reasoning.

5.4.3 Comparison with taxes and hybrid systems

This survey focuses on the use of quantity-based instruments in tackling global environmental problems. Let us briefly discuss a few points[6] concerning the comparison with taxes and then focus on a hybrid instrument recently advocated.

Threshold effects A reason for why tradable permits might be preferable to taxes in the climate change context but also for some other environmental problems is the likely existence of threshold effects. For example, ocean currents and climates that depend on them remain essentially the same provided that changes in atmospheric temperatures are not "too large," but they can change in a major way if the temperature exceeds a critical amount. Suppose there is indeed such a level of pollution below which the consequences of pollution are reversible and above which they are not and there is a permanent loss of an environmental asset. As long as the policymaker has some idea what this threshold is, she can set the total amount of permits lower than the threshold; by contrast, in a tax system, she would be required to set the tax such that pollution is less than the threshold for any possible marginal abatement cost curve. This might induce strong inefficiencies.

Uncertainty A less clear tradeoff concerns the impacts of uncertainty, in particular cost uncertainty. This point has been made first by Weitzman (1974). With tradable permits, the total amount of pollution is predictable.

[6] Another interesting result which we do not further discuss here (Klaassen 1996) is that with an international emission tax, the reimbursement of all revenues is necessary to obtain a Pareto improvement.

However, the cost to polluters of the regulation of emissions to the specificied level is not known to the policymaker. By contrast, with a pollution tax the costs is known with certainty, but the aggregate amount of pollution cannot be predicted. In situations of great political sensitivity, knowing the csost of policy intervention to industry and commerce is essential. In situations of great sensitivity of the environment to pollution, knowing the aggregate level of pollution is essential. Of course, in many cases - like in the context of climate change - both aspects are important, and so there is no a priori argument for taxes or permits out of this consideration.

Another aspect that is relevant is uncertainty about future regulations. In the SO_2 allowance trading program in the US, market participants generally regard the relatively certain regulatory environment as a plus in a market that is otherwise already exposed to significant uncertainties (energy demand, weather etc.). Some observers argue that tax systems are inherently more prone to regulatory uncertainty, although typically permit systems also do not establish property rights for permits, i.e. the government can in principle take away permits if it sees the need for it. Specific research on this issue of uncertainty about environmental regulation is missing.

Taxes and developing countries Some critics have claimed that permits are subject to a Catch-22 situation: Without trading, mitigation costs are too high to be politically acceptable; with trading, the mitigation costs are too low to be politically acceptable. Therefore, carbon taxes are sometimes promoted as being the only reasonable option (Cooper 1998). As Shogren and Toman (2000) point out, however, this approach is not a panacea for distributional concerns, in that the initial allocation of rights and responsibilities is implicit in any international control agreement, including taxes. It is also unclear whether the developing countries have enough incentives to implement higher energy taxes than exist today. Wiener (1999) offers several efficiency and political economy arguments in favor of a quantity-based over a tax-based approach.

Hybrid instruments Starting from the general work of Weitzman (1974), Pizer (1997, 1999), Hoel and Karp (1998) and Newell and Pizer (1998) show that a tax is likely to be more efficient than a permit-trading systems in the face of uncertainty for climate change. Given any particular GHG concentration, the marginal damage associated with any particular emissions rate is essentially constant. This implies little social loss from having abatement vary withthe marginal cost under a tax policy, but a potentially large lossfrom having a fixed abatement requirement in the face of cost uncertainty. (It should be noted, however, that the above argument about threshold effects goes against this line of reasoning; the empirical verdict is still out).

Combining these arguments, it is also possible to use a hybrid policy based on GHG trading, but with a safety valve of costs go too high (Pizer 2001). In practice, this policy would involve the government issuing additional permits if the price went beyond some predetermined level (which could change over time). Such a plicy can essentially equal the efficiency of a carbon tax.

5.4.4 Market efficiency

In designing emission permit trading programs, we are after social (or allocative) efficiency. If we want to rely on environmental markets to give us such efficient results, however, we must be able to rely on them in providing informational or market efficiency first. We have discusses several issues of market design in chapter 3 already. Here, we emphasize two points particularly relevant in the international context.

The market-power question While this may, in the case of a single buyer, lead to a lower amount of emissions than planned, the point is that in this way international emissions trading cannot deliver its full economic efficiency potential. A particularly important danger seems to be that Russia and the Ukraine exert such market power In a first attempt to estimate the costs of such a situation, Burniaux (1999) finds that by 2010 the price of Assigned Amount Units (the term for emission permits that the Kyoto protocol uses) would be about 20 per cent higher than under the competitive scenario (for a discussion see OECD (2001)). Clearly, the best way to avoid such situations is for governments to devolve their assigned amounts to their legal entities and promote industry-level trading (Bader 1996, Hahn 1984).

Emission permit exchanges? An issue related to the market power question is how the market for emission permits should be designed, given that there is the possibility that governments themselves act on the market. In particular, under this situation, transactions could be the result of bilateral bargaining where emission permits are not the only element of the transaction; in other words, governments will in general be motivated by other factors than strict economic ones. Prior notification by parties and, more generally, the establishment of specific exchanges has been advocated to promote competitive behavior (Bohm 1998). First experiments (Hizen and Saijo 1999) seem to indicate, however, that disclosure of contract information does generally not improve market efficiency. Similarly, trading through an exchange does not seem to improve significantly the efficiency of the trading regime as opposed to bilateral trading. These results are surprising and merit further investigation. To the extent that transaction costs take on particular shapes (for example, if there are volume discounts by brokers), initial allocations again matter for efficiency (Stavins 1995).

5.4.5 Interaction between international and domestic policies and needs

Sometimes it is argued that it does not matter how countries enforce given total emission levels domestically, as long as the allocation of quotas among countries is clear "...in principle, any domestic policy regime is possible." (Chichilnisky and Heal 2000, p. 25). Hahn and Stavins (1999) deal criticially with this important point, which has received surprisingly little attention in the literature on international environmental agreements.

They start from the observation that the Kyoto Protocol's greenhouse gas trading mechanism will lead to minimized costs if all countries use domestic tradeable permit systems to meet their national targets and allow for international trades. Thus, the European Union's proposal to introduce a trading system within Europe to fulfull the requirements of Kyoto, indeed is very important for the overall performance of Kyoto's system. By contrast, political practice suggests that many countries will use non-trading approaches such as greenhouse-gas taxes or fixed quantity standards. Hahn and Stavins show that in these cases, achieving the potential cost savings of international trading requires some form of project-by-project credit program - like joint implementation. However, large transaction costs, likely government participation, and absence of a well-functioning market may be obstacles for this toute. Overall, there is an important trade-off between the degree of domestic sovereigny and the degree of cost-effectiveness. This trade-off is not formalized in their paper yet, and it appears conceivable to use insights from the theory of federalism - which deals a lot with this kind of trade-offs - to make the argument even more convincing.

Interestingly, a survey conducted by the World Bank (for a description see Larson and Parks (1999)) found that respondents generally expect governments to use command and control measures or taxes instead of permit trading regimes to fulfill the requirements imposed on them by an international emissions trading regime. From November 1997 to February 1998, selected policy makers and potential market participants were surveyed about their expectations concerning future carbon credit markets, the policies that shape those markets and the risks associated with participating in carbon credit markets. The core survey group included companies and governments that expressed a written interest in the World Bank's proposed Prototype Carbon Fund, but also includes other potential users of carbon-credit instruments, for example, companies and business associations active on JI issues. In interviews, almost all European companies were familiar with the US sulfur dioxide emission trading program and found the results significant. Nevertheless, very few European companies though cap-and-trade regimes had a high chance of being a major component of European emissions policy. Clearly, this has changed, but it is still of historical interest because it is a factor to be considered in research on the political economy of environmental policy.

Another related issue that has been neglected in most of literature is highlighted by Schleininger (2001). He notes that the burning of fossil fuels results in emissions that both add to the global stock of CO_2 and worsen the ambient air quality. When such local externalities are present, there arises a distortion from international trade in CO_2 emissions. The maximum possible distortion is determined by the difference in factor endowment and population density of the trading regions.

5.4.6 A summary

We have discussed a wide range of issue relevant to the theory and policy of international environmental economics. The main conclusion that arises is that no unified framework yet exists to analytically capture the quite different sets of effects involved. First, we presented the Chichilnisky and Heal (1994) result that marginal abatement cost equalization need not be the correct optimality condition on the international level. A second aspect was the relationship between trade and environment, where we have trade to flesh out a few of the most relevant effects, inlcuding scale, structural, income, product, technology, and regulatory effects. Third, we discussed the ability of emisison trading to improve upon unregulated outcomes in terms of cost-efficiency. We found that indeed for the case of a uniformly mixed pollutant like CO_2, there may be possible Pareto improvements. Finally, we noted that the comparison of permit systems with taxes is not straightforward and that many factors need to be considered.

5.5 The political economy of international environmental policy

5.5.1 Different intellectual traditions

When we try to understand how environmental policy is determined in the political process, it is helpful to remind ourselves of the different historical experiences of different regions. There is a clear intellectual divide between

Europe and the U.S., at least historically: From Cambridge University, there emerged the Pigouvian tradition (which is also consistent with the French tradition in public economics and economic policy). Moreover, many European governments have typically perceived markets as part of the problem rather than as part of the solution. Up until very recently, therefore, the approach that was at the top of the European agenda was a policy based on carbon taxes. That has changed, however, with the EU's more intensive than ever explorations of possibilities for establishing a CO_2 emission trading system within Europe. The U.S., by contrast, had always beeen more strongly in the hand of the Coasian tradition which had emerged from the University of Chicago.The U.S. find the approach reflected in the SO_2 allowance trading program, the management of the distribution of lead additives to vehicle fuels, and other pollution problems consistent with the prevailing market-oriented approach to economic policy.

5.5.2 The key problem

Because the source of the risk is widespread, responsibility for resolving the problem ultimately must be shared. But the more widespread the responsibility, the greater the challenge of maintaining a stable agreement. The incentive to free ride reflects the divergence between national actions and global interests.

As such, an agreement must be voluntary and self-enforcing - all sovereign parties must have no incentive to deviate unilaterally from the terms of the agreement. In other words, successful agreements require a commitment by all major stakeholders. The rise and fall of commodity agreements, including agreements on cocoa, coffee, sugar, and tin durng the last thirty years illustrates how failure to include binding agreements from key players can erode support for the agreement (Varengis and Larson 1996, Larson and Parks (1999)). A paradox arises, because in such a situation, the greater the global net benefits of cooperation, the stronger the incentive to free ride, and a self-enforcing agreement is most easily maintained when the global net benefits are not much bigger than no agreement. A large literature has developed analyzing such self-enforcing treaties (Barrett 1994, Carraro and Siniscalco 1993, Hoel 1992).

In principle, all the lessons of game theory can be applied here, one of the key questions being when participating nations see an incentive to actually applying punishment when it is needed. At first glance it appears that at least from a theoretical point of view, matters don't look so grim, since the range of punishment instruments is relatively broad. Retaliations with trade sanctions can be viable threats in such situations (Chen 1997). However, Dockner and Long (1993) illustrate the problems that arise when many forms of sanctions exist (in this case, nations need to select a mutually agreeable set of approaches - another involved negotiation process). One interesting aspect is highlighted by Na and Shin (1998): Suppose negotiations toward international environmental agreements take place under uncertainty. If we then think about coalition formation, it is reasonable to assume that coalitions are more likely to form among countries which are similar. Since countries are more likely to be facing similar conditions ex ante rather than ex post (i.e. before the resolution of uncertainty rather than after it), the possibility of coalition formation is enhanced the sooner the negotiations take place.

While the Kytoto Protocol is more or less in place and the focus has now turned to its cost-effective implementation, for other areas of international environmental policy the question remains of how to structure the negotiations and what to expect from agreements.Barrett (2000) provides an analytical framework of this issue built around the notions of feasibility, efficiency, and stability. He argues for assumptions that conform to the real world, but that also "illuminate." Stability is a stronger condition than Nash equilibrium. Since international agreements take place in dynamic context, sub-game perfectness is required. But even this is not enough. Rather, the correct theoretical concept is renegotiation-proofness. Finally, Barrett and others have shown that "weak collective rationality" leads to the result that self-enforcing international agreements cannot always sustain first-best outcomes. The upshot of such a viewpoint is that negotiators should be strategic, and that international environmental agreements should be thought of as instruments of strategy. Also, negotiators cannot do anything about the equilibrium concept. But they can choose the feasibility constraints; they can change the rules of the game. For example, in the Montreal Protocl, the combination of trade clauses, a minimum participation clause, and side payments were such changes to the rules of the game. It appears that the negotiators of the Kyoto Protocol have been less creaticve in this respect.

5.5.3 How do we draw developing nations in?

A particularly formidable challenge is to find incentives to motivate developing countries toward a collective goal of reduced GHG emissions and indeed participate in the system at all. Equity is a key issue here. Simple rules of thumb, such as allocating responsibility according to past emissions or allocating rights in a fixed number per capita bring strong opposed interests to play, and it is unlikely that there is an easy agreement. Dynamic formulas

- that is, rules under which the control burden is a function of economic progress and thus increases for developing countries over time - have similar problems, but it has been argued that they offer more flexibility (Burtraw and Toman 1992, Schelling 1995, Yang 1999, Shogren and Toman 2000).

An important part of the process is a precise estimation of the benefits and costs for all involved parties. Ellerman, Jacovy and Decaux (1999) use empirical simulations to quantify the effects involved. Not surprisingly, they find that the effects of the Kyoto Protocol's Annex B parties' actions will depend on the particular country and on the success of emissions trading. All developing countries will have an interest in emissions trading as a source of new export earnings, but their interest will extend beyond this new commercial possibility. In particular, oil and gas exporters will have a strong interest in emissions trading as a means to reduce the cost for Annex B parties generally, and specifically to allow Annex B countries to substitute reduced coal emissions abroad for reduced oil and gas emissions at home. However, the advantage enjoued by producers of energy-intensive goods will be greater with no emissions trading, assuming that importing embodied carbon is permitted by the Annex B regions. The net balance will therefore be different for various countries, but in general it seems likely that developing countries will benefit from emissions trading. What's even more important, the gains are potentially very large, fully sufficient to give potential buyers and sellers an economic incentive to support such a system. Ellerman et al. (1999) also go on to note that an alarming distortion from the developing country standpoint is a limitation on Annex B imports of emission permits. Their study's focus is on the developing countries, so they do not evaluate the possibly positive overall environmental effect of such a limitation.

5.5.4 On the feasibility of unilateral action

According to conventional wisdom, free-riding by developing countries and leakage effects render unilateral actions by the industrial countries ineffective for global environmental problems. By contrast, Copeland and Taylor (2000) show that this is not necessarily the case for open economies. The reason is that existing treatments on trade and environment have only partly evaluated the effects of terms of trade changes. One can decompose the total effect into three distinct effects and show under which conditions higher emissions reductions by producers of “clean” goods can indeed provide an incentive for an exporter of “dirty” goods to curb emissions as well. A technical substitution effect induces free-riding. A price substitution effect induces leakage. But third, an income effect due to reduction of dirty goods production in the industrialized countries induces higher income in developing countries and thus more demand for environmental quality. This third effect may outweigh the first two effects and thus lead to an overall reduction of emissions.

6 Summary

There are substantial uncertainties in the benefits and costs of intervention through global climate change policy. The problem is made even more difficult by the very long time horizons involved and the uncertain geographic distribution of effects. In addition, there are irreversibilities, both in the climate system and in methods for controlling greenhouse gas emissions.

Despite these uncertainties, overall, assessments of the costs and benefits of greenhouse gas control suggest that limited but gradually increasing control is warranted. By contrast, immediate significant action does not appear to be justified, at least to date.

Economic analysis has strongly underscored the point that market-based policies are desirable for cost-effective greenhouse gas control. Moreover, since the costs of greenhouse gas control and mitigation vary dramatically around the globe, policies that allow flexibility in where as well as how emissions are reduced can dramatically lower the costs of achieveing climate objectives, thus leading to welfare improvements. We have surveyed the literature on one such incentive-based instrument, tradeable permits and have pointed out lessons for its use.

Issues that need to be decided are: At what level should trading be established (inputs or emissions)? How should permits be allocated (freely or via auctions)? What are the incentives for technological innovation? How can negative impacts of market power be avoided? How can an effective monitoring and enforcement framework be established? On the international level, our main conclusion was that a comprehensive analytical framework is still missing. Some of the complex issues we surveyed include: efficiency conditions in the presence of differing wealth levels; trade and the environment; impacts of permit trading on cost-effectiveness; and international political economy issues. Few of the questions we have raised have found definitive answers in research, and we look forward to seeing applications of new methods in dynamic programming, contract theory, and other areas of economics in the realm of international environmental economics.

7 Tables

Table 1: Possible impacts from climate change

Projected changes during the 21st Century in extreme climate phenomena and their likelihood	Representative examples of projected impacts (67%-95% probability)
Higher maximum temperatures, more heat waves (90-99% chance)	Increased incidence of death and serious illness in older age groups and urban poor Increased heat stress in livestock and wildlife Increased risk of damage to crops Increased electric cooling demand
Higher minimum temperatures (90-99% chance)	Decreased cold-related morbidity and mortality Decreased risk of damage to some crops, increased to others Extended range and activity of some pest and disease vectors
More intense precipitation events (90-99% chance)	Increased flood, landslide, avalanche, mudslide damage Increased soil erosion
Increase in tropical cyclone peak wind intensities (66-90% chance)	Increased risks to human life, risk of epidemics, coastal erosion
Increases Asian summer monsoon precipitation variability (66-90% chance)	Increased flood and drought magnitude

Source: IPCC (2000).

Table 2: Milestones in international climate change policy

Year	Event
1979	First World Climate Conference in Geneva
1990	First Assessment Report of the IPCC: significant uncertainty as to impact of human activities
1990	Second World Climate Conference, agreement to work towards a framework treaty
1992	Earth Summit (UNCED) in Rio de Janeiro. Annex I developed countries pledge to return to 1990 emission levels by 2000
1995	IPCC Second Assessment Report completed; stronger conviction expressed that human activities adversely affect climate
1995	Conference of the Parties (COP) 1 in Berlin: work towards targets and timetables
1997	COP 3 in Kyoto. Annex I, Annex B countries agree to binding emission reductions averaging 5% below 1990 levels by 2008-12 with "flexibility" mechanisms (including emissions trading) for compliance
1997	Byrd-Hagel resolution by U.S. Senate: The US will accept no climate agreement that does not demand comparable sacrifices of all participants; ratification of Kyoto Protoocol must be justified with benefits and costs
1998	COP 4 in Buenos Aires, operationalizing the market-based instruments
1999,2000	COP 5 in Bonn, COP 6 in the Hague. Deadlock.
2001	US President Bush repeats opposition to the Kyoto Protocol. COP 7 in Marrakech (see text)

Source: Kolstad and Toman (2002).

Table 3: Instruments of environmental policy and criteria to evaluate them

	Instrument		
Dimension	Emission Charges	Tradable permits	Regulation
Cost efficiency	+	+	-
Environmental effectiveness	-	+	+
Administrative practicability	+	+	+
Dynamic efficiency	+	+	0
Political acceptability	0	0/+	+

"+"=high, "-"=low, "0"=neutral.
Source: Klaassen (1996)

Table 4: Conditions affecting cost efficiency and environmental effectiveness

	Cost efficiency			Environmental effectiveness		
	Charges	Permits	Regulation	Charges	Permits	Regulation
Uncertainty about costs	-	0	-	-	0	?
Imperfect markets	-	-	?	-	0	?
Transaction costs	0	-	0	0	0	0
Imperfect enforcement	0	-	?	0/-	-	-
Discontinuous control	0	0	-	-	0	0
Cost-saving techn. Progress	-	0	?	?	0	0
Economic growth	0	0	0	-	0	-
Inflation	0	0	0	-	0	0

"-"= negative impact; "0" = no impact; "?" = unknown
Source: Klaassen (1996)

Table 5: Economic instruments and their effect on incentives for innovation

Determinant	Emissions Tax	Grandfathered permits	Auctioned permits
Abatement cost effect	+	+	+
Imitiation effect	-	-	-
Emissions payment effect	None	None	+
Adoption price effect	None	-	-

Source: Klaassen (1996)

Table 6: Tradeable permit systems (Stavins 2000)

Country	Program	Traded Commodity	Period of Operation	Environmental and Economic Effects
Canada	ODS Allowance Trading	CFCs and Methyl Chloroform; HCFCs; Methyl Bromide	1993-1996; 1996-present; 1995-present	Low trading volume, except among large methyl bromide allowance holders
	PERT GERT	Nox, VOCs, CO, CO2, SO2 CO2	1996-present; 1997-present	Pilot program; Pilot program
Chile	Santiago Air Emissions Trading	Total suspended particulates emission rights trading among stationary source	1995-present	Low trading volume; decrease in emissions since 1997 not definitely tied to TP system
European Union	ODS Quotat Trading	ODS production quotas under Montreal Protocol	1991-1994	More rapid phaseout of ODS
Singapore	ODS Permit Trading	Permits for use and distribution of ODS	1991-present	Increase in permit prices; environmental benefits unknown
United Kingdom	Emissions Trading Program	CO2 emissions	2002-present	Unknown

United States	Emissions Trading Program	Criteria air pollutants under CAA	1974-present	Performance unaffected; savings = \$5-12 billion
	Lead Gasoline Phasedown	Rights for lead in gasoline among refineries	1982-1987	More rapid phaseout of leaded gasoline; \$250 m annual savings
	Water Quality Trading	Point-nonpoint sources of nitrogen and phosphorus	1984-1986	No trading occurred because ambient standards not binding
	CFC Trades for Ozone Protection	Production rights for some CFCs, based on depletion potential	1987-present	Environmental targets achieved ahead of schedule; effect of TP system unclear
	Heavy Duty Engine Trading	Averaging, banking, and trading of credits for Nox and particulate emissions	1992-present	Standards achieved; cost savings unknown
	Acid Rain Reduction	SO2 emission reduction credits; mainly among electric utilities	1995-present	SO2 reductions achieved ahead of schedule; savings of \$1 billion/year
	RECLAIM Program	SO2 and Nox emissions among stationary sources	1994-present	Unknown
	N.E. Ozone Transport	Primarily NOX emissions by large stationary sources	1999-present	Unknown

Table 7: Lessons for the use of market-based systems

1	Allow for a broad set of compliance alternatives.
2	Make the system transparent and simple.
3	Use absolute baselines.
4	Implement effective monitoring and enforcement.
5	If a tradeable permit system is used, aim to avoid free allocation of permits.
6	Use a market-based instrument if abatement costs vary widely.
7	Be mindful of factors affecting the effectiveness of instruments (e.g. transaction costs)

Table 8: A typology of environmental effects of increased trade

	Direction of effect on environmental quality
Scale effects	Positive if increased trade goes hand in hand with compensating product, technology developments
Structural effects	Ambiguous
Income effects	Increased willingness to pay typically has positive effects; but ambiguous findings on environmental Kuznets curve
Product effects	Ambiguous
Technology effects	Ambiguous
Regulatory effects	Improved policies, but also increased pressures on policy by trade agreements

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