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New and old market-based instruments for climate change policy^{*}

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Abstract

We review and examine three market-based instruments for addressing the challenge of climate change: emission trading, emission taxes, and hybrid instruments. Our main contribution is the illustration and comparison of these instruments using recent results from theoretical research and practical policy experience. Hybrid policies that aim to combine taxes and permits emerge as a promising way forward. An additional contribution is that we also comment on two other related concepts, namely, innovation strategies and prediction markets. For the former, we show that, to make economic sense, the much publicized Asia-Pacific Partnership on Clean Development and Climate has to rely on the same basic tool as the other instruments, namely, relative prices. For the latter, we discuss how prediction markets can complement traditional scenario analysis by experts. They are likely to improve the practical implementation of all previously discussed methods.

Keywords: Climate change, market-based policies, prediction markets, tradable permits, emission taxes, innovation

JEL-code: G18, Q0, Q48, Q54

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1 Introduction

Unabated climate change threatens to fundamentally change and indeed worsen quality of life on this planet: Measures of global temperature show that average temperature has augmented by about 0.74 degrees Celsius ($^{\circ}\text{C}$) in the last 100 years, while the number and the frequency of extreme weather events like heat waves, meagreness, strong rainfalls and tropical storms has increased. For a scenario of no mitigation of greenhouse gas (GHG) emissions, the increase of the global average temperature is estimated to be around 0.2 $^{\circ}\text{C}$ per decade (IPCC 2007). In November 2006 the Stern Review (Stern 2006) presented a dramatic scenario that could happen if nothing changes in the context of climate protection. The concentration of GHG in the atmosphere is about 430 parts per million (ppm) carbon dioxide (CO_2), compared to 280 ppm CO_2 before the Industrial Revolution. This concentration leads to an increase of global temperature by more than 0.5 $^{\circ}\text{C}$ and will lead to a further increase of at least 0.5 $^{\circ}\text{C}$ over the next few decades. If annual emissions do not increase above today's rate the GHG concentration will reach 550 ppm which will probably lead to an increase in global temperature by more than 2 $^{\circ}\text{C}$ (Stern 2006). To stabilize the GHG concentration at 550 ppm the global emissions will have to decrease by about 25% above today's level. For a stabilisation at 450 ppm the decrease will have to be 70% until the year 2050 (Stern 2006).¹ Similarly, the IPCC predicts scenarios of a slow increase in globally averaged surface temperature between 1.1 and 2.9 $^{\circ}\text{C}$ and scenarios of an extreme increase between 2.4 and 6.4 $^{\circ}\text{C}$ for the 21st century (IPCC 2007). A stabilization of the GHG in the atmosphere between 445 and 535 ppm CO_2 in 2030 would cost maximally about 3% of the global GNP. In the third IPCC's assessment report an increase of global temperature by 1 $^{\circ}\text{C}$ was equated with a global loss of about US\$ 214 trillion over the next fifty years. In the year 2050 alone, damages of about 2 trillion US\$ have to be expected (IPCC 2001).² Of course, there is great uncertainty attached to these

¹ For a critical discussion of the Stern Report concerning issues of the rate of discount and cost-benefit-analysis see Tol (2006) and Nordhaus (2006).

² Although climate change is a global problem, its impacts are often best appreciated by policymakers and citizens alike when broken down into effects for their own country. To illustrate the impact of climate change in Europe to readers in Asia, some results for Austria and Germany shall be considered by way of example: Vienna is faced with a doubling of tropical days above 30 $^{\circ}\text{C}$ daily high temperature within the next 50 years. The frequency of higher maximum temperatures has increased in Vienna in the period of 1951-2000 compared to the period 1901-1950. The Schmittenhöhe (a well-known ski area) on the other hand is faced with a reduction of ice days with daily high temperature below 0 $^{\circ}\text{C}$ by one third (Kromp-Kolb 2003). Numbers for Germany show that the increasing numbers of natural disasters will lead to

estimates, but Weitzman (2009) shows that the economic consequences of fat-tailed structural uncertainty (along with unsureness about high-temperature damages) can readily outweigh the effects of discounting in climate-change policy analysis, thus calling for urgent action.

Because of the importance of the problem, much literature has dealt with optimal ways to address climate change with economic tools. It has long been recognized that command and control instruments (like fixed standards over inputs, outputs or technologies or location controls) are inadequate to obtain the desired reduction of emissions in cost-minimizing ways. Therefore, we focus on market-based instruments that hold the promise of cost-effectiveness.

This paper reviews and investigates the theoretical setup and practical workings of three different ways of possible actions against climate change, reveals operating experience. The main contribution of the paper is that it reviews, following the same criteria for all instruments, and drawing on the most recent available findings, all three of these basic instruments. While some reviews of individual systems are available, there exists, at least to our knowledge no current article that compares all three systems in one place. But such a comparison is important because using a partial approach it is relatively easy to critique (or favour) one system not keeping in mind that it may dominate (or be dominated by) other systems on another dimension. We study tradable permits, emission taxes (and subsidies), and a hybrid between permits and taxes. We cover the basic workings of emission trading and emission taxes (subsidies for reductions) only rather briefly as a lot of literature is available on them. The third instrument – less known in Europe but important in the policy discussion in the US – is a hybrid instrument that combines trade and tax systems to optimize the advantages the two former systems have. The recent experience in Europe is of significant interest also for the Asian economies. We argue that the European Emission Trading System (ETS) has likely failed in achieving efficiency in its first phase – too many permits were allocated for free. This resulted in too high emissions in the ETS sector and produced additional burden to mitigate pollution in the non-ETS sector. It may also have led to a lacking incentive to engage in emissions trading on the firm level. Hybrid policies are likely to be attractive for future policy adjustments because they allow scarce initial

damages of about 137 billion Euros until the year 2050 (Kemfert and Praetorius 2005). A study by the ETH Zurich and Swiss Re found that the damages through winter storms in Europe will increase until 2085 up to 68% from 1975 values (SwissRe 2006).

allocations of permits while still giving sufficient safety to industry, should abatement costs turn out to be unexpectedly high.

Our second contribution is that we challenge a much-publicized approach focusing on technological progress. The governments of Australia, Canada, China, India, Japan, South Korea and the US are in favour of this approach as a complement to the Kyoto protocol. They have documented their preference for this approach recently through the founding of the Asia-Pacific Partnership on Clean Development and Climate (APP). Because of the dual characteristics of this strategy – technological progress and international diffusion – we refer to this approach as the innovation and cooperation strategy.³ Little specific information is available yet on this partnership, and it is to some extent still obscure what exactly is the operational approach that is to be taken. What is clear after our analysis, however, is that this approach, too, will have to rely on a working price system.

Because all policy tools are strongly affected by uncertainty and difficulties to predict future outcomes, we also propose to establish a “prediction market” for future technologies. On such a market, claims on the likelihood of various technological innovations are traded, thus using the aggregate knowledge of all market participants in addition to relying on estimates of policymakers or a few experts.

We begin in section 2 with an explanation and evaluation of the different economic instruments that support the fight against climate change. The emphasis here is on efficiency and effectiveness. Section 3 takes account of the instruments with respect to several additional important dimensions, including ecological effectiveness and political feasibility. In section 4, we focus on the issue of uncertainty and propose prediction markets as an effective complement to existing ways of forecasting the future. Section 5 concludes.

2 Overview of market-based methods to fight climate change

In contrast to many textbooks and general surveys, we especially direct our attention to issues relevant to Europe in order to see how the policies implemented fit with the recommendations of economic theory; this in turn can then enrich our discussion of

³ There are other instruments that we do not discuss. Perhaps the biggest omission is that we do not further deal with carbon sequestration and reforestation. We refer the reader to Lecoq and Chomitz (2001), Lubowski et al. (2006), Stavins (1999) and Stavins and Richards (2005).

policy not only for Europe but also for other countries, including countries in Asia. Because of the prominence of the debate in the US, but not in Europe and in Asia, we spend considerable time laying out the operation mode and crucial issues of implementation of a hybrid policy. At the end of the section, we discuss a strategy that focuses on innovation and cooperation. Although this strategy is advertised as a new approach by the APP, at least from the currently available documentation of that partnership, the strategy appears to be consistent with and indeed a logical corollary of the other three approaches.

2.1 Emission trading

Emission trading is one of the flexible mechanisms of the Kyoto-Protocol and shall therefore play an important role in reaching international climate targets. The Kyoto-Protocol's provision for an international cap-and-trade system paves the way for the implementation of the regional emission trading system in Europe (Stavins 2008). One important point why emission trading was chosen to help reach the Kyoto-Targets is that, like taxes, it allows emissions to be reduced where it is cheapest for the economy, i.e., it is cost-effective (Dales 1968; Montgomery 1972). In a framework where permits are allocated for free, an emission trading system does not involve transfers from the private sector to the government vis-à-vis an emission tax approach.

The basic setup is that a regulator sets an emission cap for a certain sector. The level of this cap depends on the target that should be achieved. The more ambitious the target, the lower the overall cap is. When the overall cap is set, each participator - the individual firms - will get a certain allocation of emission allowances. This allocation can happen in two different ways. The first one which is used in the EU ETS is grandfathering. With this method, emission rights are mainly allocated on base of past emissions of each company. The alternative is to auction off allowances. We discuss these two approaches below.

In general, the EU ETS covers installations which are combustion plants, oil refineries, coke ovens, iron and steels plants and factories producing cement, glass, lime, brick, ceramics and pulp and paper. Sectors or industries which are not covered by the scheme, e.g. the private sector, transport or the building industry, have to be regulated by other (national) abatement measures in order to reach each national emission reduction target. To illustrate the quantities involved, Table 1 shows the

allocated emission allowances of some large European companies. It becomes clear that because of the size of the market even a low or mediate price of allowances is substantial, as is the potential cost for each individual company.

Table 1: Emission allowances allocated to some European companies

Sector	Company	Allocated allowances (in thousand tons CO ₂)		by National Allocation Plan of
		2005-2007	2008-2012	
Steel	ThyssenKrupp Stahl AG	48,190	98,552	Germany
	Voestalpine	34,069	56,710	Austria
Electricity	EnBW Kraftwerke AG	30,237	33,880	Germany
	Vattenfall Europe Generation AG & Co. KG	198,607	187,887	Germany
	Verbund	10,033	12,519	Austria
	EdF	64,535	80,835	France
Refinery	OMV	8,303	14,960	Austria
	Shell	10,616	25,131	UK
	BP	11,582	25,103	UK
	Esso	10,871	16,591	UK

Source: NAPs of the different countries

To put the role of the emission trading program into perspective with the overall amount of emissions, it is instructive to consider the overall amount of CO₂ emissions, which are shown in Table 2. Emission trading in the European Union only covers a part of these emissions. In the EU-ETS, emission allowances for approximately 2.2 billion tons of CO₂ were allocated per year for the period 2005-2007 while within the period 2008-2012 emission allowances for approximately 1.9 billion tons of CO₂ - without accounting for changes in the captured installations and sectors by the scheme - have been allocated per year.

Table 2: CO₂ emissions of different regions (in million tons)

Year	World	EU-15	EU-27	China	India	Japan	South Korea
1995	23,108	3,277	4,141	3,013	916	1,305	374
1996	23,903	3,355	4,242	3,216	999	1,328	408
1997	24,118	3,301	4,154	3,157	1,042	1,322	424
1998	24,905	3,347	4,142	3,022	1,070	1,287	364
1999	24,083	3,321	4,076	2,735	1,140	1,318	396
2000	24,677	3,349	4,100	2,740	1,155	1,344	431
2001	24,918	3,418	4,179	2,800	1,181	1,341	438
2002	25,874	3,409	4,155	3,532	1,226	1,328	446
2003	27,020	3,488	4,263	4,146	1,264	1,376	454
2004	28,424	3,508	4,283	4,881	1,343	1,391	466
2005	29,430	3,486	4,258	5,380	n.a.	1,401	n.a.
2006	30,047	3,466	4,258	5,944	n.a.	1,381	n.a.
2007	30,892	n.a.	n.a.	6,389	n.a.	1,393	n.a.

Source: Eurostat, IWR (Internationales Wirtschaftsforum Regenerative Energien), Umweltbundesamt, United Nations Statistics Division

The second way to allocate the allowances is via complete or partial auctioning. Companies bid for the amount of emissions they would probably need and have to buy the certificates. This is generally seen as the preferred way of doing the allocation. (For an overview about the concepts of grandfathering and auctioning we refer the reader to Cramton and Kerr (2002).) First, auctions are more cost-effective in the presence of certain kinds of transaction costs. Second, the revenue raised can be used to reduce other distortions. Note also that instruments such as tradeable permits can create entry barriers that raise product prices, reduce the real wage, and exacerbate pre-existing labor supply distortions. This effect can be offset if the government auctions the permits, retains the scarcity rents, and recycles the revenue by reducing pre-existing distortionary taxes (Goulder and Bovenberg 1996).⁴ Third, auctions provide greater incentives for firms to develop substitutes of CO₂-intensive technologies. Fourth, due to the revenue raised by auctions, administrative agencies may have a bigger incentive to monitor

⁴ In economic literature, this mechanism is called the “Double Dividend”. The “Double Dividend” of an emission tax or an emission trading system results on the one hand from reducing emissions (ecological dividend) and on the other hand from increasing welfare via using the revenues from the tax or the auctioning of permits to diminish existing tax distortions (economic dividend). For an overview regarding the double dividend hypothesis the reader is referred to Goulder (1995).

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 (Deweese 1983). For all these reasons, an auction of emission rights may be preferable to grandfathering which could lead to the conclusion that the EU-ETS is likely to be highly inefficient currently on this dimension.

In practice, and taking into account the political process, the auctioning of permits may not be preferred to grandfathering. One common assumption is that the regulated industries would oppose auctioning. But this is not the only possibility. For example, Lai (2008) considers the lobbying behaviour of interest groups and shows that industrial lobbies may endorse an auction while environmental lobby groups may support grandfathering of permits. In this framework, a cost-minimizing industry endowed with few free permits favors an auction because this allocation rule strengthens its political influence and empowers the industry to lobby for a greater share of the emission cap or rather a higher amount of permits and in consequence minimize the permit price.⁵

Within the revision and the preparation for a post Kyoto period of the EU-ETS one central point is the intensification of auctioning allowances from 2013. The proposal of the EU-Commission concerning the revision of the EU-ETS considers a replacement of the limited use of auctioning allowances (a 5%-cap in the first and a 10%-cap in the second trading period) by an auctioning of at least 60% of the total number of allowances which consists of a full auctioning approach within the power sector and a partial auctioning of 20% for energy intensive industries.⁶

When the initial allocation is done trading can start. Companies which have more certificates in their portfolio than they need - net suppliers - can sell these certificates on the market to companies – net purchasers - which have to cover their emissions with additional permits. Thus, the certificate price results from the interaction of the supply of certificates (the emission cap) and the demand behaviour of emitting firms (the

⁵ Lai (2008) shows as well that grandfathered permits will raise the industrial endowment effect and strengthen the environmental group's lobbying power. Hence, in the case that the emission cap is defined in subsequent stage, environmentalists will support grandfathered permits within this public choice context. The empirical analysis of Svendsen (1999) arrives at the conclusion that environmental lobby groups in the US advocate grandfathering in order to arrange stricter reduction targets.

⁶ We cannot deal with the whole revision process concerning the centralization and harmonization of cap setting and allocation rules, the enlargement of the scope, the competitiveness of covered sectors and the integration of third countries to increase the effectiveness of the EU-ETS in this paper. For an overview, we refer the reader to Ellerman and Joskow (2008) and Convery (2009).

aggregate marginal abatement costs). In principle, in the presence of perfect information, no transaction costs, a perfectly competitive trading market and no governments' interventions trading will result in the economically efficient outcome independently of the initial distribution of permits (Montgomery 1972), because marginal abatement costs are equated in any equilibrium.⁷ Conversely, this independence result does not necessarily hold when there is uncertainty (and firms are risk-averse), when there are transaction costs, when some firms have market power in either allowance or product markets or when firms receive different regulatory treatment. Also, when some market participants are not cost-minimizing or when current allocations are tied to production in previous periods, allocations may matter (Hahn and Stavins 2009).

Some recent work has considered to which extent emission markets operate efficiently. An active market has developed for allowances on the European CO₂ market (Parsons, Ellerman and Feilhauer 2009); this liquidity is a necessary condition for market efficiency. One consideration in this context concerns transaction costs. The existence of transaction costs can lead to a wedge between market participants' marginal costs. Thus, allowance prices diverge from the zero transaction cost competitive equilibrium.⁸ Another question is whether prices are, in fact, unpredictable, as the efficient markets hypothesis suggests. Applying technical analysis and naïve forecasts, Daskalakis and Markellos (2008) show that three of the most important spot and future markets for European CO₂ allowances deviate from the weak form of market efficiency. That is, returns of CO₂ allowances exhibit predictability and simple trading

⁷ By contrast, Chichilnisky and Heal (1994) 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 the marginal cost of abatement in each country to be inversely related to the 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 for efficiency, not merely for distribution, if environmental quality has a direct impact on wellbeing and marginal valuations of private goods differ strongly across countries.

⁸ Cason and Gangadharan (2003) use laboratory experiments to show that in a setting with decreasing marginal transaction costs the prices and traded quantities vary less from the efficient level if the initial distribution of allowances is not accomplished cost-effectively. The reason is that a more deficient distribution of allowances is in need of a higher transaction volume to accomplish the cost-effective allocation which induces lower marginal transaction cost in a framework of decreasing transaction costs. Furthermore, in the case of constant marginal transaction costs, transaction prices and traded quantities are independent of the incipient endowment.

methods can be applied to generate significant risk-adjusted profits. These findings may be traced back to the facts that the EU ETS currently still suffers from immaturity and features constraints regarding short-selling and banking.⁹ A third consideration is the intertemporal efficiency, i.e., the link between spot and futures prices. Accounting for price dynamics of CO₂ future contracts of the EU ETS, Uhrig-Homburg and Wagner (2009) find that spot and futures prices were linked by the cost-and-carry approach between December 2005 and the end of the first trading period.

In the long run, direct and indirect linking of the EU-ETS with other regional or national systems will offer an opportunity to increase liquidity of and participation in the market for tradable allowances, thus improving the functioning of the market. By an intensified linking of the EU-ETS any given global reduction target could be implemented at lowest cost (Jaffe and Stavins 2007). Further, the linking of separate tradable permit systems could form an important element of a post-2012 climate policy architecture and endorse negotiations about ecologically more effective reduction targets (Jaffe et al. 2009). In the short term the EU-ETS has focused on (indirect) linkage with emission reduction credit programs like the Clean Development Mechanism of the Kyoto - Protocol.

2.2 Emission Tax

The emission tax is a near relative of emission trading.¹⁰ While emission trading focuses on the amount of emissions which are allowed in general, the emission tax focuses on the price side of this relation. As the different companies have different abatement costs they will react in different ways to an emission tax. Some companies will reduce more than others. If the tax is higher than the marginal costs of abating, at least a part of the emissions will be reduced by a company. This will happen as long as the tax rate is as high as the costs of abating the next unit of emissions. If the tax rate is chosen in a way that is as high as the price would be in an emission trading scenario, then there would be no difference between these two ways of climate protection.

⁹ Ellerman and Montero (2002) empirically evaluate the temporal efficiency of the U.S. Acid Rain Program allowing for trading and banking. They find that in contrast to the general perception of excessive banking in this program banking worked efficiently.

¹⁰ Subsidies essentially work symmetrically, and we do not explicitly discuss them here. Olsson et al. (2006) discuss them in the European context and provide experimental evidence on their competitive impacts.

Calculating the optimal tax rate (or the optimal level of emissions with a tradable permit program) of course requires substantial knowledge about benefits and costs of mitigating emissions. Applied to the context of climate change, what is the optimal policy? Cline (2004) found a path for optimal carbon tax and optimal percent cutback in emissions with the DICE99CL model. He found that an optimal abatement strategy should be very aggressive with an emission cutback of about 35-40% in the early stages, increasing to 50% by 2100 and 63% by 2200. Therefore adequate carbon taxes would be necessary which should be about US\$170 per ton around the year 2005, rising up to US\$246 by 2025 and US\$367 by 2055. It is obvious that these numbers are of a different order of magnitude than what is being discussed right now for possible CO₂ taxes.

2.3 Hybrid systems combining emission trading and emission taxes

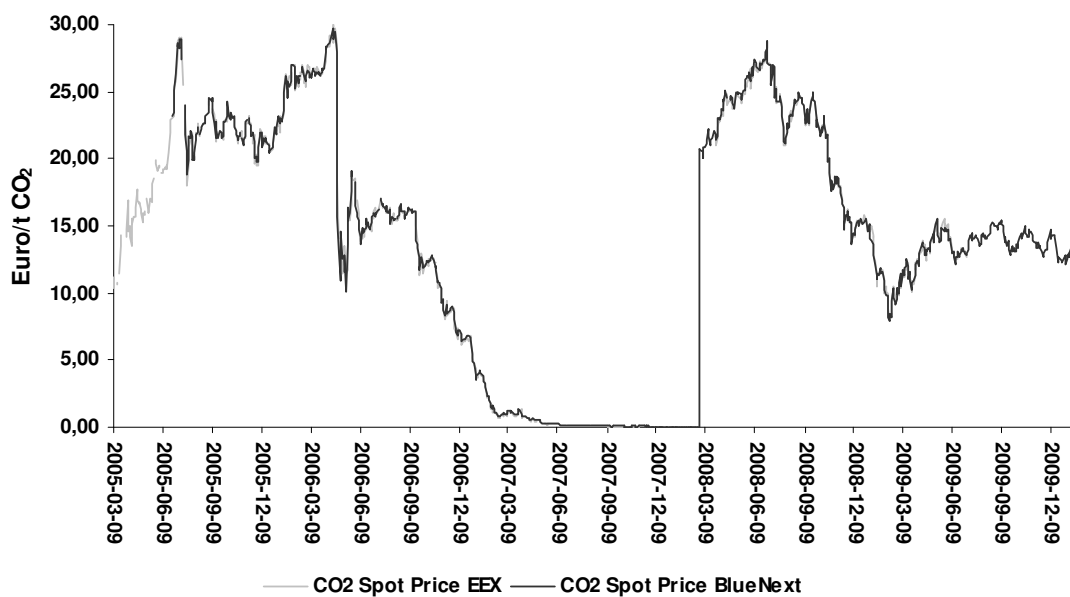
The prices which could be seen on the European CO₂ market are of a different order of magnitude than the prices calculated by Cline (2004). In the following Figure 1, we present the Intraday Spot Price from the start of emission trading at the EEX (European Energy Exchange) and BlueNext on March 9th 2005 up to the most recently available data.

As one can see from the data presented in this figure, during the year 2006 the range of the emission permit price has varied between €10 and €30, which is far away from the emission prices that have been calculated by Cline (2004). Even in that time period, we can thus conclude that the EU-ETS does not achieve social (or allocative) efficiency. The cost-effectiveness of the reduction may also have been constrained simply because little reduction of emissions was required. Trading did take place (in fact, trading volume in the ETS rose more quickly than it did at the start of the SO₂-permit trading program under the Clean Air Act amendments of 1990 system) but in the absence of a baseline of how much trading should have occurred, it is hard to evaluate the outcome.

The price path of CO₂ permits in the EU is not only noteworthy for its level but also for its highly volatile behaviour. Despite the fairly low expectations of maximum price caps of about €15 the permit price climbed up to €30 until spring 2006. A few days later, the information that the market as a whole was “long permits” began to circulate, meaning that too many permits were allocated. This emerging of an overallocation in the trading sector of the EU-ETS resulted in a price collapse unusual for commodity

markets. This episode illustrates that there is significant uncertainty in the market. Part of it probably has to do with the fact that emission trading is a new policy for Europe, but part is inherent in the way the market is set up. Because of banning the possibility of transferring permits from one trading period to another by most member states and the resulting loss in value of the CO₂ permits with the new trading period in 2008, the price effects following from over allocation were intensified.¹¹ (See Parsons et al. (2009) for a discussion of this problematic design feature.) Nonetheless, even without these institutional features there is significant uncertainty. The spot price ranging initially between €22 and €27 illustrates the increased value of CO₂ permits generated by stricter allocation caps for the second trading phase.

Figure 1: Spot price of a ton of CO₂ permits on the European market, in €¹²



Source: BlueNext, EEX

The key assumption that drives the equivalence between emission permits and emission taxes in the previous two sections is the absence of uncertainty. In particular, the regulator was assumed to know exactly what upper bound to set on emissions or

¹¹ The so called banking of emission allowances shifts permit trading into future trading periods and consequently represents an instrument of risk management with respect to drastic price changes and allowance shortages (Maeda 2004). For an analysis of the reduction of abatement costs via a banking of permits in the Kyoto framework, see van Steenberghe (2005).

¹² On January 21st 2010, the exchange rate was €1 ≈ US\$1,41.

what tax rate to set in order to achieve the social optimum. The price is defined by the tax in that way that the optimal level of abatement is generated while the quantity-based approach can be used to fix the optimal quantity in order to generate the market price. In practice, however, uncertainty is rampant. Indeed, both the (marginal) costs of abatement of greenhouse gas emissions and the (marginal) benefits of avoiding climate change are highly uncertain. For example, Pizer (2002) calculates that the marginal cost of achieving the 1990 emissions level in 2010 would involve a marginal cost between US\$0 and US\$180 per ton Carbon¹³ (for a 95% confidence interval). The marginal benefits are approximately constant independent of the reduction of emissions, and are between US\$0 and US\$24 per ton Carbon.

As Weitzman (1974) shows in his seminal paper, price instruments (like taxes) and quantity instruments (like emission permits) behave asymmetrically in the presence of benefit and/or cost uncertainty.¹⁴ In this setting, an environmental agency has to choose the instrument of pollution control ex ante with regard to the expected degree of welfare being generated ex-post. Weitzman's main result is that taxes minimize the deadweight loss from choosing the wrong policy if the marginal costs of abatement are steeper than the marginal benefits, while emission permits are preferred otherwise.¹⁵ Because of the features of cost and benefit functions in the context of climate change, some researchers therefore argue for the superiority of taxes as a policy instrument for climate change. Intuitively, because marginal costs are assumed to be steeper than marginal benefits, taxes are preferable because they put a fixed upper bound on the costs firms will have to bear. By contrast, emission permits may produce, in equilibrium, an extremely high price that may create substantial overall efficiency losses.¹⁶

In a dynamic setting, Biglaiser et al. (1996) show that under the assumption of complete information a quantity based approach may not induce a the social optimum even if the market is perfectly competitive because an optimal system of tradeable permits exhibits time inconsistency. By contrast, tax approaches to regulate pollution may be able to achieve the social optimum and feature time consistency. Montero (2002) shows that with incomplete enforcement and cost and benefit uncertainty, a

¹³ One ton carbon corresponds to 3.67 tons CO₂.

¹⁴ We comment on other differences below.

¹⁵ The analysis of Adar and Griffin (1976) using quadratic cost and benefit functions provides the same results while Weitzman's findings are based on approximately quadratic cost and benefit functions.

¹⁶ Newell and Pizer (2003), for example, find that taxes generate up to nearly 5 times the expected welfare gains of tradable permits in a 40-year horizon.

quantity instrument performs relatively better than a price instrument; when marginal benefit and cost curves having the same slope, the quantity instrument should be preferred. The reason for this preference is that incomplete enforcement is endogenous to the actual cost of control. Under incomplete enforcement unexpectedly high costs cause non-compliance of some firms, and thus the advantage of prices over quantities is mitigated. On the other hand, Newell and Pizer (2003) find that in a setting of stock pollution with rising optimal stock levels the more efficient control is often provided by a price-based approach. Overall, there is no definitive advantage of either prices or quantities; the relative dominance depends on the circumstances.

Economists have long considered ways of combining the advantages of emission trading with the advantages of emission taxes (Roberts and Spence 1976).¹⁷ One such hybrid instrument uses certificates as the main instrument, but there is a backup system that should protect the participating companies from an extreme increase in prices for the permits. This backup system works with a so called “safety valve” that gives companies the possibility to buy permits from the national authority at a fixed price that is usually higher than the expected market price. For the case that the market price does not develop as expected, companies have an option to buy certificates at a fixed price. This makes it easier for companies’ calculations as they have an overview of the maximum costs they may be faced with. Companies can choose whether to buy permits at the market or to buy them from the national authority, but their choice will depend on the market price. But if the market price is higher than the trigger price companies will pay the trigger price, to the national authority which can be seen as a tax per unit of emission. As long as the price of the permits is below the trigger price the system will work like a trading scheme providing cost efficiency with uncertain costs and a fixed amount of emissions. If the trigger price is reached because of higher abatement costs than anticipated a so called “safety valve” is provided and the system changes to a tax scheme with fixed costs but an uncertain outcome of emissions. Roberts and Spence (1976) show that the simultaneous implementation of price and quantity approaches

¹⁷ We do not deal with a combination of market-based instruments with environmental standards for certain regions here. The aspect of a combination of permit trading and ambient concentration limits is considered by Krupnick et al. (1983) and McGartland and Oates (1985). The SO₂-permit trading program under the Clean Air Act amendments of 1990 and the usage of a tradable permit system for NO_x and SO₂ under the Regional Clean Air Markets (RECLAIM) in Los Angeles can be cited as real implementation of a combination between a tradable permit approach and environmental standards (Snyder Benneer and Stavins 2007).

minimizes expected total costs in contrast to the isolated usage of a price-based or quantity-based instrument. The application of this hybrid system can be interpreted as protection of each instrument against the malfunction of the other.¹⁸

Figure 2 shows how the hybrid system works (cf. Jacoby and Ellerman (2000)). The national authority allocates permits in the amount of Q_1 . Marginal social costs of emissions are described by MSC. If the marginal abatement costs are low, as is shown by the marginal abatement cost curve 1 (MAC_1), the market price for certificates will be P_1 . But if marginal abatement costs turn out to be high as is shown by the marginal abatement cost curve 2 (MAC_2), the resulting market price would be P_2 . This is much higher than expected, leading to an efficiency loss, because the quantity of permits should have been higher. This is where the hybrid policy comes in. In this policy, companies can buy additional permits from the national authority without limit at a safety valve price P_{SV} , and overall costs will be much lower as in an emission trading system. Due to the higher level of abatement costs emissions are abated to level Q_H and permits in the amount of $Q_H - Q_1$ are bought.

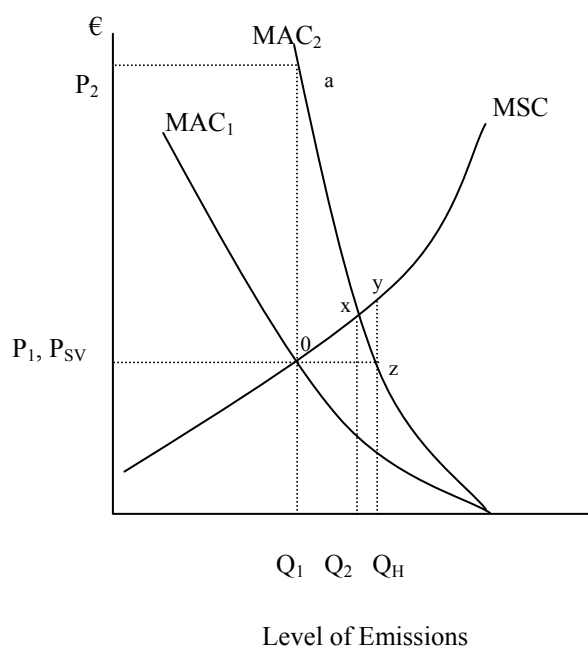
Finally, the level of emission under the hybrid system Q_H will be slightly higher compared to the optimal level of emission Q_2 which leads to lower total costs under the MAC_1 and higher social cost of the emission level within the range between Q_H and Q_2 . The welfare efficiency loss of the hybrid system (the area $x - y - z$) is less than that what would have appeared in the situation without the safety valve (the area in the triangle $0 - x - a$). Therefore, the hybrid system gives companies more security concerning the financial side of the system, because they know a maximum amount of costs that will arise if the trigger price comes into play.

In the economic literature the implementation of a hybrid system lately has been seen as an important approach fighting global climate change (Jacoby and Ellerman 2004; McKibbin and Wilcoxon 2002; Pizer 2002). The efficiency gains from the hybrid policy for climate change have been estimated to be substantial. Pizer (2002) uses a modified version of the Nordhaus (1994) DICE model. It is true that the hybrid policy only slightly improves on the pure tax system; the expected social benefits of a global policy to combat climate change are about US\$300 billion in both cases. But both the

¹⁸ Baumol and Oates (1988) study a hybrid system which allows the firms to sell their permit to the government if the price falls below a certain "price floor" which however can back dynamic inefficiencies up.

tax and the hybrid system are dramatically superior to the optimal tradable permit solution, by a factor of five or more. Thus, given that the hybrid system has a significant appeal vis-à-vis the tax system – namely, the ability to flexibly distribute the rents associated with emission rights – it appears as a very attractive option indeed.¹⁹ To our knowledge, there is no analysis of the relative gains of this instrument specifically for Europe.

Figure 2: A hybrid system



How high the trigger price should be is a matter of ongoing discussion. Some argue that the trigger price should be high so that it is getting used only in unexpected situations, when the demand for emission rights increases as a result of unexpected actions. But if the trigger price is set too high, the basic problem of a deadweight loss in the case of unexpectedly high marginal abatement costs arises. On the other hand, if the trigger price is set too low, not all marginal benefits of reducing emissions are internalized. Numerical results confirm this intuition. For example, Pizer (2002) calculates that the optimal trigger price actually is very similar to the optimal tax level.

¹⁹ A drawback of this prototypical hybrid system is that it necessitates monetary exchanges between the private sector and the government in case the trigger price is reached (which may be seen categorically as a bad idea). Newell et al. (2003) consider policies that replicate the behaviour of the policy without monetary exchanges.

If, in 2010, the same world emissions as in 1990 should be obtained, he calculates that the optimal trigger price is around US\$20 per ton carbon.²⁰

2.4 The innovation and cooperation strategy

We now turn to what at first appears like a completely different way of possible climate change policies, but what, in the end turns out not to be a separate instrument on its own. The idea behind this strategy has entered public discussion with the consultation of the Asian-Pacific-Partnership on Clean Development and Climate (APP). This agreement between Australia, Canada, China, India, Japan, South Korea and the US is focusing on a new way to achieve climate protection hand in hand with economic performance. The partners of this agreement want to focus on the development of new technologies and an increased cooperation both on developing and distributing these technologies. The idea the governments involved in this partnership had when they founded this partnership was that innovation of new technologies reduces greenhouse gas emissions which helps them to fulfil their climate protection targets and provide a higher level of energy security. As a side effect of these technology advances, indeed, economic theory suggests that only technological progress can boost economic growth in the long run.²¹

Since July 2008, 123 projects have been registered in which government agencies and companies from the sectors of aluminium, buildings and appliances, cement, cleaner fossil energy, coal mining, power generation and transmission, renewable energy and distributed generation and steel are involved. Some illustrative examples of the APP's project activities include the management of bauxite residue in the aluminium production, the promotion of a standardized energy efficient lighting, the transformation of waste to fuel in cement kilns, and the improvement of carbon capture technology for coal-fired power plants. Furthermore, it covers the development of strategies to guarantee health and safety in coal mining, the implementation of a shared

²⁰ Recall that these estimates are based on what is seen by many as an inefficient goal of emissions reductions themselves. Cline's (2004) estimates above optimize both the quantity and the price.

²¹ This was recognized already in Solow (1956). Only more recently did economists think about how technological progress develops endogenously. The seminal contribution is Romer (1990), but a huge literature, which we cannot review here has since followed. We refer the reader to Barro and Sala-i-Martin (2003) for a comprehensive overview.

best practice approach in the power generation sector, and the intensification of the usage of solar power and cleaner steel technologies.²²

The basic question, though, is what are the incentives for technological progress? Like for any other economic activity, people may have intrinsic incentives, but for most entrepreneurs engaging in the business of technological innovation, there is also an extrinsic part. A useful framework for thinking about technological progress has been provided by Schumpeter who separated technological progress into three different phases. The first one is called invention and is defined as the phase in which new ideas are created. In the second phase these ideas have to be developed into commercially useable products. This phase is called innovation. All these innovations can only push an economy forward if they are widely used. This happens in the third phase of the cycle of technological change named diffusion. The critical point is that each of these phases is guided and regulated by incentives. Incentives come from outside effects like (relative) prices or official regulation.

One way to interpret the APP is that it wants to give the same relative incentives as other, existing policies in Europe and elsewhere, but with a different method. In particular, one interpretation is that it favors rewarding environment-friendly technologies rather than punishing environment-hostile technologies. Economically, the effect is the same and the two approaches are isomorphic, but politically, they may be worlds apart. Where the first three approaches discussed in this paper use taxes and quantity restrictions, it is likely that the Asia-Pacific partnership would favor research subsidies. They might also consider a policy innovation such as “minimum number of inventions bonds” (the rough equivalent of a quantity instrument).²³ These instruments would be set with very similar goals in mind as discussed before: social efficiency and cost-effectiveness.

Of course, participating countries tend to have different interests concerning environmental protection and economic development. Therefore, as a common

²² Detailed information of the different sectoral projects and outcomes of the 8th Policy and Implementation Committee Meeting in October 2009 can be found under <http://asiapacificpartnership.org/default.aspx>.

²³ Recall that an emission permit allows a company to emit a ton of a particular pollution, thus causing social damages. Similarly, with an “invention bond” a company would be allowed to receive the right to use a new technology. Companies that are not innovative enough to invent themselves are better off buying these bonds, leading to a more efficient social allocation. Clearly, this is rather utopian, but the basic principle should apply here.

environmental target is missing in contrast to the Kyoto-targets, each country will try to maximize its utility, which may inhibit the effectiveness of the Asia-Pacific partnership being based so much on cooperation. Moreover, one problem with subsidies is that they can be misappropriated fairly easily. La Porta et. al (1999) indeed show a positive correlation between government transfers and subsidies and corruption, although the overall evidence and interpretation of this correlation is less clear. Buscaglia and van Dijk (2003) found that “high levels of corruption are associated with high distortions and abuse of discretion in the granting of state subsidies to the private sector”. Olsson et al. (2006) discuss further implementation issues if subsidies were to be used in Europe. One aspect that we cannot deal within this paper is how the international diffusion of technological progress is governed. Difficult issues in industrial organization, international intellectual property law, and other areas are relevant here, and they have to be analyzed separately.²⁴

In short, we challenge the view that this is a separately viable economic instrument to combat climate change. Not only is it relatively obscure how precisely this approach would be put into operation, but it is also clear that it is practically meaningless without a price system that is supported by one of the three core approaches discussed earlier.

3 Additional criteria for choosing among instruments

So far, we have discussed the four instruments mainly in the light of efficiency and cost-effectiveness considerations. All market-based instruments are likely to yield cost-effective solutions, and their efficiency always depends on the degree of information the policy maker can secure regarding optimal pollution levels. In this section, we consider additional criteria for choosing among instruments, in particular, ecological effectiveness, political feasibility, financial impacts, and dynamic incentives. It is important to evaluate these criteria for all instruments at the same time. In evaluating the instruments, we also draw, on existing experiences especially in Europe. As

²⁴ Recent work has revealed that a technology transfer from a developed country (north) to a developing country (south) in a situation with no-trade the north country will, in equilibrium, and even if the technology is transferred free of costs, always like to transfer the technology to the south. The south will always be better off if it accepts the technology. In this case, the global pollution level will always stay within the initial levels. In a second step trade was introduced between north and south and different outcomes were found. In this two-commodity model, the north is specialized on the production of the non-polluting commodity and south is specialized in the production of the polluting commodity. The north could be better off if it transferred technology but once it decides to transfer than it would be done completely. The technology transfer cannot guarantee a stable global emission level under a trading scenario (Mukherjee and Rübhelke 2006).

discussed earlier, uncertainty is perhaps the dominating aspect of climate change policy and therefore an extremely important criterion for evaluating policy choices. It permeates all the issues discussed in this section. We have studied one important aspect (the question of deadweight losses) above, and we will return to the issue of uncertainty again in section 4, where we ask how we can approach it using a market-based instrument.

3.1 Ecological effectiveness

Ecological effectiveness describes how well an instrument works to reach the environmental goal the policy focuses on. Emission permits and emission taxes, which are near relatives to each other, have one of their biggest differences in this point. Emission trading sets an overall cap of emission allowances that are supplied to the companies which have to take part in the system. This cap is limiting overall emissions from the emission trading sector. Ecological effectiveness therefore is, at least in theory, one hundred percent as no more emissions than allowed should be emitted. (That does not mean that one hits the right target – but society is able to achieve it for sure.) As emission trading is a new instrument in European environmental policy not much experience has been gained yet. Experiences in the United States with an SO₂ trading system which started in 1995 have shown that the allowance trading program had positive welfare effects, taking into account both ecological and economic aspects, with benefits six times greater than costs (Stavins 2003). As mentioned earlier, while the quantity is fixed (at least to the extent that emissions can be properly measured), the price of emissions and abatement is uncertain.

In contrast to an emission trading system, an emission tax system cannot guarantee an exact amount of emissions as the outcome. The reason is that with a fixed price of emitting that is set by the tax and unknown marginal abatement costs, the reduction of emissions is uncertain. The reduction can be higher than in a trading system if the tax is higher than the market price but the reduction can be lower as well if the tax is below the market price. Ecological effectiveness of a tax system depends on the tax rate which should be set ideally with the knowledge of the marginal abatement costs. Usually these costs are only available to each individual company but not to the authority and therefore the tax has to be set without this information. Thus meeting an environmental target with a tax is difficult and the tax has to be adapted until the initial target is

reached. This trial and error process will need time and is difficult in a political context if the system of emission taxes is not commonly agreed upon under all political parties. In other words, the standard, static uncertainty analysis by Weitzman (1974) and others that was already discussed above has to be extended by including dynamic aspects. But if the deadweight losses in one period of time turn out, ex post, to have been too high, then in the next time period the instrument may be adjusted. However, even if adjusting the tax rate would be socially optimal, this adjustment is not necessarily possible in the political process. In other words, political inertia can be an additional cost of choosing the wrong tax rate in the first place.

Experiences with taxes in Europe have shown different results. In Norway, for example, high carbon taxes have led to low effects on emissions. This may be because the tax does not work for the sources in which it was levied and was not used for other sources where it would have worked (Bruvoll and Larsen 2004). For Germany simulations for the effects of the ecological tax reform have shown that a reduction of CO₂-emissions can be achieved while still reaching increasing employment. In the model, CO₂-emissions are reduced step by step until they are 3 % lower than in the business-as-usual scenario without an ecological tax reform in 2010 whereas GDP will increase up to nearly 0.5 % and employment will increase around 0.75 % compared to the business-as-usual scenario (Kohlhaas 2005).

The hybrid system combines the trade and the tax systems not only in institutional settings but also in the issue of ecological effectiveness. Thus, the ecological target is reached as long as the hybrid system is moving in the trade area of the system. If the trigger price rather the safety valve are reached and additional certificates can be bought from the national authority the certificate cap is increasing and the ecological target gets diluted as the outcome is not clear anymore. One can see that consequently the ecological effectiveness of the hybrid system depends on the setting of the trigger price. If the trigger price is set near the market price for emission allowances then a little demand increase is sufficient to increase the price for the allowances over the trigger price. In this case, allowances can be bought from the national authority and the ecological target is missed. So the policy should be designed with a trigger price high

enough that it is only reached in unpredictable situations to keep the focus on the environmental effect of the system.²⁵

Ecological effectiveness is a problematic point in the innovation strategy. The output of research and development, one of the most important points in a good working innovation strategy, cannot be easily predicted. The potential that new inventions have to protect the climate are hard to foresee in advance. It is impossible to say that new inventions in the next 10 years will reduce emissions by 50 % because nobody knows exactly what environmental protecting potential new inventions will have. As there are no binding goals in this strategy the whole ecological effect will depend on the progress of technology, on the intensity of international cooperation, and on the exchange of technologies between countries or even companies. All these aspects are hard to predict. We will return to this issue, and especially the possibility to forecast future technologies using market-based tools, in section 4.

3.2 Political feasibility

Political feasibility means the acceptance a policy has in the public. If more (and more powerful) people are in favour of a certain policy, it is easier for the political authority to implement this policy without compromising their chances for re-election – the latter of course being one major incentive for governments in their choice of policy instruments.

One relevant factor influencing the feasibility of a policy is the number of people that is affected by the policy. For example, in the case of a tax this factor is defined by the amount of money which costs the tax each individual. In the case of emissions this paper is focusing on, that means how the broad public or the majority of voters are affected by emission trading, taxes or other policies. But as interest groups play an important role in political decision making small lobbies may be powerful when it comes to negotiations about new political activity. Representatives of the industry sector, which is made up of only few people in comparison to, e.g., the large number of workers that are represented by the unions, may have a lot of political power because of the capital they represent.

²⁵ Murray et al. (2009) pick up the potentially insufficient ecological effectiveness of a cap-and-trade system with a safety valve and suggest an allowance reserve approach. This system provides a fixed price ceiling and a maximum number of permits to be issued which means that the ecological target is supported by ensuring a quantitative limit of permits.

In the case of emission trading as it is used today most people are not directly affected. In Europe only large companies in electricity generation and industry have to take part in the emission trading system but small businesses and households are excluded. From this point of view emission trading has a good political enforceability. Voters are indirectly affected, however, through increasing prices which are a result of the higher costs companies are faced with. But as it is difficult for consumers to have an exact view of the reasons for increasing prices in detail, emission trading can be seen as an instrument relatively easily implemented. Stavins (2007) argues that environmental advocacy groups (generally supporting command-and-control instruments) strongly prefer tradeable permits vis-à-vis a tax approach because the price-based policy generates highly visible cost of environmental protection. Regarding the permit allocation, an allocation without charge may be easier to implement than taxes or auctioned permits, because the industry's mitigation cost are less visible and less burdensome. Further, free allocated permits alleviate forming majority coalitions by providing more control to regulate the distributional effects.²⁶

It may, however, also be the case that people do not like the uncertainty that goes along with new policies. In this case, they will be more opposed than they should be. Of course, that argument may be moderated once one considers the active and powerful role lobbies, sometimes of small, but important constituencies, play in shaping the policy process and its outcomes.

Taxes are frequently seen with scepticism. Thus, introducing an emission tax has to be done carefully if a government does not want to lose its mandate with the next election. As it is the case in a trading system the number of people who are directly affected by the tax will cause the acceptance of the tax and the chances for the government of re-election. As additional taxes on emissions will increase the prices of different goods, amongst others electricity, nearly all people are affected at least indirectly by such a policy.²⁷

²⁶ With regard to the political economy of market-based environmental policy, we refer the reader to Joskow and Schmalensee (1998) who examine the political process of permit allocation within the U.S. Acid Rain Program.

²⁷ There is little systematic evidence on how people feel about environmental taxes. Halla et al. (2008) analyze how satisfaction with democracy in European countries varies with environmental quality and policy. They find that citizens in countries in time periods with higher environmental or energy taxes tend to be less satisfied with the way democracy works in their country, but citizens are more satisfied if more environmental policies are enacted. They explain this result with the fact that a measure of the

A hybrid policy is, as the trading policy, a strategy that is not well known among the broad population. At least in terms of its principles, it can be “sold” as something other than a tax, giving it a natural advantage. The empirical analysis by Pizer (2002) shows that a hybrid system is only little more efficient than a pure tax approach. But with regard to political feasibility the hybrid policy may be favourable to a pure price-based approach because on the one hand it provides (in the case of gratis allocation) acceptance within the industry sector and on the other hand generates the possibility distribute the rents generated from the additionally sold emission allowances (Snyder Benneer and Stavins 2007). It should thus be easier to implement it without too much protest in a bigger part of the population.

The political enforceability of different systems can be very different from country to country. On a general level, as Europeans are more used to taxes as a regulating instrument, it is easier to implement such a hybrid instrument compared to the United States where taxes are seen as an evil from the very first idea and a lot of work has to be done to convince people from the benefits of such a system. From this perspective, it is quite puzzling that Europe adopted an emission trading program for CO₂ in the first place.

How much the public is concerned by a hybrid system depends on its design. The number of companies or individuals who are affected depends on the approach that is used. If an upstream approach is used, much fewer companies are affected because the system starts working at the top of the carbon chain, namely importers and producers of fossil fuels while a downstream approach affects many companies and individuals as the duty of providing certificates is shifted into the direction of the end-users (Boemare and Quirion 2002). Furthermore, the choice of sectors that are regulated by a trading system affects the public. It makes a difference if only the energy sector is captured by an emission trading system or if public and especially private transports are included.

From the political side, the innovation strategy seems to be the easiest one to implement. Companies are not faced with any binding reduction targets or taxes and therefore prices for energy and products which require fossil resources do not increase as a result of the policy. As technological progress and innovation is a positive sign for an economy political authorities will find it easy to support R&D without compromising

quality of democracy is how well it resolves collective action problems, but that by and large individuals prefer not to pay for environmental quality.

their chances for the next election campaign. However, once one thinks about the second part of the innovation strategy, namely, the coordination of technology transfer, one becomes more doubtful about the ease of implementation. Loosely speaking, every country has an incentive to free-ride. Worse, that incentive is not only present in the technology-sharing phase, but already in the innovation phase. In the worst case, all incentives for technological progress might evaporate.

3.3 Financial impacts

Financial impact in this context means how consumers in a country with a regulation policy are affected of this policy in monetary circumstances. As all policies increase costs of companies more or less, the question is how companies will pass on these costs to consumers.

The practical experience with emission trading in the European Union has shown that, although emission certificates were allocated for free, companies have integrated the costs for certificates as opportunity costs into their calculation and prices have increased (Woerdman 2001). That is what we have seen in practice since the start of the European emission trading scheme, especially in the electricity sector. Sijm et al. (2006) show by empirical estimates that the pass-through rates of costs of CO₂ allowances for the power sectors in Germany and the Netherlands varies between 60 and 100% depending on the carbon intensity of the marginal production unit and various other market- or technology-specific factors. The German “Verband der Industriellen Energie- und Kraftwirtschaft” reported in May 2006 that the German energy sector makes an annual surplus of €5 bn. by including the price of certificates into their electricity price calculation (Kraftwirtschaft 2006). For the UK, calculations show an increase of the wholesale power prices of £3,50 - £10,50 / MWh over the forecast period to 2020 as a result of these windfall profits.²⁸ This should increase the profit of the UK power generation sector by £800 m per year (Industry 2005). In theory, the ecological effects of regulation and the financial impacts should be the same as with a tax policy and who has to bear the additional costs should depend on the slope of the respective supply and demand curve.

In the hybrid system the same logic applies. Companies are faced with higher costs as a result of the policy, and they may be able to pass on the costs. Whether companies

²⁸ On January 21st 2010, the exchange rate was £1 ≈ US\$1.62.

or consumers are paying the bigger part again depends on the slope of the demand and supply curves.

For the R&D policy it is difficult to predict the financial impacts. First they depend on who is financing R&D, government or companies. If we talk about public financed R&D, it is clear that it has to be financed through taxes. Thus taxes have to be either increased (which is frequently distortionary and thus creates social costs) or public expansions have to be cut in other areas to leave taxes unchanged. Firms can engage in R&D on their own to realize comparative advantages. The government may also decide to motivate companies, if firms do not engage in a socially efficient level of R&D on their own. As we will discuss in more detail in the next section, incentives for companies to start R&D activities can precisely come from an emission trading program or from taxes, both of which increase the price of emitting CO₂ and force companies to find measures not to pay these additional costs.

In terms of political feasibility, R&D promotion through lower taxes or tax deductions has the advantage of neutrality concerning decisions about the topic and the character of R&D-projects on the companies' part. Taxation benefits are only a little barrier for companies to get in favour of financial support, which is especially important for small and middle sized companies. The conditions to get a benefit are transparent compared to other methods of public support, and for companies it is easy to plan because the rules of getting a tax reduction are known in advance (Hutschenreiter and Aiginger 2001). However, in contrast to an innovation program where a fund is fixed for each period a tax incentive provides losses in tax revenues which lead to higher or new taxes to compensate this loss.

3.4 Dynamic incentives

Besides analyzing the static cost efficiency of environmental instruments also the generation of dynamic incentives to technological change and innovation play an important role whereas the innovation and cooperation strategy is not the only policy that requires the consideration of dynamic aspects. Other policies should also be designed to encourage companies to improve their emission reduction techniques continuously. Market-based policies such as tradable permits and taxes not only have

static cost-effectiveness advantages, but also dynamic incentive advantages.²⁹ Snyder et al. (2003) show empirically that change of relative prices induced exogenously or by the implementation of a certain policy may provoke technological change and thus, the achievements of different policy instruments can vary. In general, it is important to assess the effects of a pre-existing framework of regulation while evaluating the effects of alternative instruments on technology innovation and diffusion.

An emission tax provides a continuous incentive for reducing emissions, because every unit of emission that is not emitted saves money for the company. As long as reduction measures are cheaper than paying the tax, companies will engage in research to reduce emissions or adopt existing emissions-reducing technologies. An emission trading systems provides, in principle, the same dynamic incentive as a tax system. Every unit of emission a company does not emit provides an additional certificate saleable on the market. Thus, companies are interested in reducing emissions because it also reduces their costs.

But within the analysis of an emission trading system with respect to the dynamic incentives a distinction regarding the possible allocation metrics has to be made. Under the assumption that the diffusion of new technologies reduces the demand of permits relative to the supply and therefore also the permit price, grandfathering diminishes the incentive of emitters covered by the system to evolve environmental innovations. The higher the diffusion of new technologies, the higher the value of the permit and the benefits from selling surplus permits is reduced so that a free allocation constrains the dynamic incentives. By contrast, the auctioning of permits generates the incentive to use new technology because in the long run costs from purchasing permits can be reduced (Milliman and Prince 1989).

As a hybrid system combines tax and trade systems it also has the dynamic incentive of continually increasing reduction efforts. As in the two former cases the dynamic as a whole depends on the price. The higher the price or the tax the longer a dynamic incentive to reduce emissions is given.

²⁹ Other policies should also be designed to lead companies to improve their emission reduction techniques continuously. Recall that in the case of an emission standard companies do not have any incentive to improve their technology once the level set by the authority is reached. This policy, which is not part of this paper, has no dynamic incentive at all. For an empirical analysis concerning the dynamic incentives of environmental regulation by taxes, technology adoption subsidies and technology standards we refer the reader to Jaffe and Stavins (1995).

The dynamic incentives of the innovation strategy depend on the design of the R&D policy. If R&D is supported by national authorities the direction of R&D activities can be guided as well as the range of the different sectors that should be covered by the activities. The dynamic incentive or the incentive to permanently increase the level of technology depends in some way on the will of the authority and the financial support it is providing to R&D. If a national authority is interested in a permanent technological improvement, the financial, organisational and political background must be provided. If these preconditions are set, the chances for a permanent progress in environmental technology are given.

4 Dealing with uncertainty

As discussed earlier, both emission permits and taxes are cost-effective instruments, i.e., they allow society to achieve a specified quantity or price goal at minimum cost. We have discussed earlier how the economic efficiency of emission permits and taxes depends on the quality of information the regulator has about benefits and costs, and how hybrid instruments have been proposed to combine the best of both. For the innovation and cooperation strategy, it is much more difficult to predict even theoretically what will happen, simply because innovations are, by nature, hard to predict. There is a very strongly market-based tool that allows feasible policy decisions precisely in such a context which is called “prediction markets.”

It has long been known that speculative markets do a great job of aggregating relevant information. In fact, they often perform better than forecasting institutions. Already Roll (1984) pointed out that orange juice futures improve on weather forecasts. Horse race markets beat horse race experts (Figlewski 1979). The Economic Derivatives market run by Goldman Sachs and Deutsche Bank outperforms economists in predicting economic outcomes (Gürkayanak and Wolfers 2005). Oscar markets (e.g., the Hollywood Stock Exchange) make more accurate predictions than columnists (Pennock, Giles and Nielsen 2001). Both real and play-money markets have generated more accurate forecasts of the likely winners of NFL football games than all but a handful among 2000 self-professed experts (Servan-Schreiber et al. 2004). Election markets beat national opinion polls (Berg, Nelson and Rietz 2001). And corporate sales markets beat corporate sales forecasts (Chen and Plott 1988). Prediction markets have also been applied to forecast influenza outbreaks (Nelson, Neumann and Polgreen

2006). In all of these cases, we are in a similar position as we are when trying to predict which technology will next be invented and adopted in the case of technology that allows us to diminish greenhouse gases.

Wolfers and Zitzewitz (2008) provide a survey of recent research on prediction markets. Scholars have considered how to translate market prices as probabilities, for example (Wolfers and Zitzewitz 2005). Intuitively, if more people expect a (well-specified) event will happen, more people will buy an asset that pays off 100 if that event happens. For example, suppose we construct a market where an asset is traded that pays off 100 if the average CO₂ emissions of cars fall below 50g/km. It is unknown if and when such a technology becomes available. However, the market price of such an asset is likely to give policymakers and other firms a good indication of how likely it is. Obviously, there are many implementation issues to be dealt with in this context, e.g., what is the exact sample of cars that is considered; is it just prototypes that count (in the spirit of Schumpeter's innovation stage) or is it only mass-produced cars; etc. Hanson (2003) shows that even though there may be many thousands or millions of combinations of events that a market might trade, it is still feasible to construct a liquid and informative market. Finally, issues of moral hazard (while having played an role in the closing of the Policy Analysis Market in the US in July 2003 (Hanson 2006)) are generally not seen as insurmountable obstacles.

Another issue may also be of concern to policymakers. In some sense, prediction markets establish a derivative market in that the price of the entity being traded depends on the probability that the "underlying," namely, the technology comes into existence. There is a long, but inconclusive discussion in finance and economics whether the introduction of derivatives, such as futures, leads to increased volatility of the underlying. Some have found such an effect; others the opposite; yet others have found no effect.³⁰ Consider the introduction of a prediction market in a market where firms are already subject to a tradable permit system, such as a in Europe. Conceptually, what might happen is that the technology prediction market leads to more volatile views on

³⁰ Seminal contributions showing an increase in spot price volatility due to derivatives trading include Figlewski (1981), Stein (1987), Harris (1989) and Lee and Ohk (1992). By contrast, Bessembinder and Seguin (1992) and Brown-Hruska and Kurserk (1995) provide evidence suggesting that active futures markets are associated with decreased stock market volatility. Finally, Santoni (1987), Edwards (1988a) and Edwards (1988b) find that daily and weekly volatilities of the S&P 500 are not different after the introduction of futures. Darrat and Rahman (1995) and Darrat et al. (2002) also found no correlation of S&P 500 and DJIA jump volatility with derivatives trading.

abatement technologies, thus leading to more volatile emission permit prices. There is, to our knowledge, no study that specifically addresses this concern in the context of prediction markets. An overall assessment of this consequence would also have to determine what economic costs arise from more volatile emission permit market prices and how they compare to the benefits obtained from the prediction market. In particular, firms may suffer from more volatile spot prices. However, volatilities can be hedged with appropriate instruments, and the cost to firms would therefore consist primarily in the costs of the hedge. (Chesney and Taschini (2008) provide an approach for CO₂ option pricing, for example.) As the market for options on emission permits grows more liquid, this cost decreases, but it will still remain an important factor. Understanding the overall welfare effects of prediction markets in this specific context thus remains an important area for research.

In short, prediction markets in principle appear as an extremely important complement to other market-based policies for combating environmental problems that are surrounded by a great deal of uncertainty. The one potential drawback seems to be an increased volatility of emission permit prices, although existing research indicates that it is far from certain that derivatives are responsible for increased spot market volatility. More detailed analysis of this possibility must be left for future research, but it seems clear that especially the innovation-based strategy would tremendously benefit from being accompanied by a market-based forecast of technological innovation and diffusion.

5 Conclusions

All three basic strategies that are presented in this paper show a potential for addressing climate change. Emission trading has a clear goal concerning the reduction of emissions as the overall cap of allowed emissions is set at the beginning. Environmentalists may favor emission trading from a purely ecological viewpoint, because with help of the cap it is possible to control the total amount of emissions. Controlling the amount of emissions is more difficult using an emission tax. In this case the regulator has to have information about marginal abatement costs of the individual companies and the whole economy. This information is hardly known, so that the optimal tax rate to achieve a certain target has to be set in a trial and error process,

which is hard to implement from a political point of view. Because there is much evidence that the marginal cost curve is steeper than the marginal benefit curve in the context of climate change, efficiency considerations at first favor taxes, but a hybrid system, i.e., a permit system with a safety valve, may do very well, too. We have discussed how the different instruments can be evaluated with respect to various criteria. Importantly, they are all cost-effective, but they vary with respect to ecological effectiveness, financial impacts, dynamic aspects, and political feasibility. The substantial advantages of the hybrid approach, on a theoretical, practical, and political-economic level lead us to regard this instrument as very promising for the post-2012 period in Europe.

On the international level, climate change is combated by the Kyoto-Protocol, an international agreement linked to the United Nations Framework on Climate Change between industrialized, emerging, and developing nations. The Protocol's major feature is the provision of binding targets for industrialized countries for reducing GHG emissions to an amount of an average of 5% against 1990 levels over the five year period 2008-2012. However, the implementation of the Kyoto-Protocol has been criticized by economists with respect to the missing participation of key countries of the global GHG emission, the short time path of action and the inexistence of firm-level market-based policy instruments (Olmstead and Stavins 2008). Key principles regarding the negotiation process of a post Kyoto agreement are the establishment of a global cap-and-trade-approach connecting regional and national tradable permit systems and consequently integrating developing countries. Further, a harmonization of domestic actions to combat climate change should be induced by a portfolio of international treaties and an international adjustment of carbon taxes. Besides the development of a particular climate policy framework, the promotion of technology transfers and deforestation, the reformation of Kyoto's CDM (Clean Development Mechanism) and a linkage between global climate policy and global trade policy are inevitable issues of a future arrangement (Aldy and Stavins 2008).

We have also given an economic interpretation of the ideas expressed in the basic mission statement of the Asia-Pacific Partnership on Clean Development and Climate. This partnership intends to promote technology as a way to deal with global environmental problems. Probing deeper, one recognizes that the drivers of all three Schumpeterian phases of technological progress – invention, innovation, and diffusion –

are incentives. Promoting clean energy alone with good will most likely is not going to be enough as long as fossil energy is cheaper. Therefore using taxes or trading to make fossil energy more expensive is a way to set an incentive that helps to develop cleaner technology quicker than it would without such financial incentives. A useful complement to emission taxes and emission permits are subsidies and quantity-based tools that promote technological progress. To our knowledge, no analysis equivalent to the many studies analyzing optimal emission taxes and permits is available for the subsidies approach.

Existing studies have a hard time incorporating the notion that technology will change over time. More generally, environmental policy, in particular such long-term policy as that related to climate change, has to struggle with the significant uncertainty surrounding benefits, costs, and available technologies. Environmental effects of technologies in development can be estimated but not predicted for sure. From the experience of such diverse areas as weather forecasts, horserace betting, macroeconomic variables, and elections, we know today that “prediction markets” – i.e., markets where assets are traded whose value depends on the probability that a certain event happens – can play a powerful role in providing effective advice. In particular, they can aggregate information, often more accurately than experts can. While this market could conceivably lead to more volatile emission permit prices, the potential advantages available by a more effective knowledge and information aggregation mechanism also appear large.

6 References

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